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BACKGROUND

The dawning era of Space Station *Freedom* (S.S. *Freedom*) payload operations requires a reassessment of traditional modes and methods of conducting payload operations. The relatively short duration of Spacelab missions has often resulted in rather intense crew operations which are planned to the minute in order to accomplish science requirements and work around in-flight contingencies. The increased on-orbit time that will eventually be available during the S.S. *Freedom* mature operations should allow more operational fexibility and will render impractical the minute by minute scheduling approach. Both ground and flight crews will need added flexibility in the planning and implementation of longer duration operations.

PURPOSE

The main purpose of this study was to develop and analyze potential methods of creating payload resource envelopes at the individual experiment level. Resource envelopes incorporate additional resources into the activity schedule to allow operational flexibility. Methods identified are not end points but rather are intended to stimulate thought, discussion, and evaluation. Another purpose was to determine whether the resource envelopes could be implemented manually or if additional software would be required.

SCOPE

The study is applicable to mature S.S. *Freedom* payload operations. The reference experiment models presented are for example only, as are the analytical assessments of implementing the various potential methods. This study was undertaken, and the concepts were developed prior to the restructuring of the S.S. *Freedom* program.

STUDY DESIGN/APPROACH

Four Spacelab experiment activity models, designated M01, M22, M10, and A26, were chosen to illustrate potential resource envelope methods. Three of the activity models, M01, M22, and M10, were assumed to represent a typical Spacelab microgravity experiment. Model A26 is a single activity experiment which represents a typical space station solar observation.

The four models were selected for this study because their resource requirements are representative of the requirements for multiple discipline space station activities. The models require varying levels of power, crew, microgravity, and equipment usage. Model A26 requires observation opportunities and has variable step durations. The models were analyzed for crew and power resources only; however, it is realized that in practice all resources would have to be addressed.

The four models are divided into steps which are described in tables 1 through 4. The second column of each table provides a brief description of the step. The duration of each step is listed in the third column. The power level required for the step is listed in the fourth column. The number of crew required for each step is listed in the fifth column.

Table 1. Activity model description – M01.

STEP	DESCRIPTION	DURATION (min)	POWER LEVEL (Watts)	NUMBER OF CREW
1	CE Power On, Bit Check	5	80	1
2	Remove Dummy Cartridge Install Sample Cartridge	10	80	1
3	Heater Traveling Stow Dummy Cartridge	3	120	1
4	Fore Vacuum Venting	15	108	0
5	High Vacuum Venting	15	108	0
6	Heat-Up	60	870	0
7	Temperature Holding	60	613	0
8	Temperature Holding and Heater Traveling	540	395	0
9	Controlled Cooling	200	218	0
10	Gas Cooling	89	80	0
11	Heater Traveling	6	120	0
12	Fore Vacuum Venting	1	108	0
13	Dry Air Supply	3	108	0
14	Remove Sample Cartridge Install Dummy Cartridge	10	80	1
15	CE Power Off	2	80	1

Table 2. Activity model description – M22.

STEP	DESCRIPTION	DURATION (min)	POWER LEVEL (Watts)	NUMBER OF CREW
1	CE Power On, Bit Check	5	80	1
2	Remove Dummy Cartridge Install Sample Cartridge	10	80	1
3	Heater Traveling Stow Dummy Cartridge	3	120	1
4	Fore Vacuum Venting	15	108	0
5	High Vacuum Venting	15	108	0
6	Heat-Up	40	870	0
7	Temperature Holding	43	747	0
8	Temperature Holding and Heater Traveling	457	409	0
9	Controlled Cooling and Heater Traveling	40	366	0
10	Gas Cooling	121	80	0
11	Heater Traveling	4	148	0
12	Fore Vacuum Venting	1	108	0
13	Dry Air Supply	3	108	0
14	Remove Sample Cartridge Install Dummy Cartridge	10	80	1
15	CE Power Off	2	80	1

Table 3. Activity model description – M10.

STEP	DESCRIPTION	DURATION (min)	POWER LEVEL (Watts)	NUMBER OF CREW
1	CE Power On, Bit Check	5	80	1
2	Remove Dummy Cartridge Install Sample Cartridge	10	80	1
3	Heater Traveling Stow Dummy Cartridge	3	120	1
4	Fore Vacuum Venting; High Vacuum Venting	30	108	0
5	Heat-Up	60	460	0
6	Temperature Holding	10	355	0
7	Temperature Holding and Sample Mixing	10	369	0
8	Temperature Holding and Heater Traveling	36	395	0
9	Controlled Cooling	24	355	0
10	Temperature Holding and Heater Traveling	30	395	0
11	Gas Cooling	84	80	0
12	Heater Traveling	6	107	0
13	Fore Vacuum Venting	1	82	0
14	Dry Air Supply	3	82	0

Table 4. Activity model description – A26.

STEP	DESCRIPTION	DURATION (min)	POWER LEVEL (Watts)	NUMBER OF CREW
1	Pointing and Mode Setting for ASO	10	0	1
2	Begin Observation	5	750	1
3	Solar Observation by ASO	50/65	750	0
4	Pointing and Mode Setting for ASO	10	0	1
5	Begin Observation	5	750	1
6	Solar Observation by ASO	50/65	750	0

A summary of the models is provided in table 5. The number of steps in the model is listed in the second column. The run time allowed for the activity is listed in the third column. The fourth column provides the energy consumption for the activity. The amount of crew time required for the activity is listed in the fifth column.

The power profiles for the four reference models are depicted in figure 1. These profiles illustrate that the power requirement for the models vary over time. Models M01, M22, and M10 require power, at varying levels, throughout their entire duration. Model 26 requires a constant level of power for steps 2, 3, 5, and 6, but requires no power for steps 1 and 4.

The crew profiles for the models are depicted in figure 2. As can be seen from the profiles, models M01 and M22 require crew for the initiating and terminating steps. Model M10 requires crew only at the beginning of the experiment. Model A26 requires crew at the beginning and near the middle of the experiment.

Table 5. Resource consumption summary.

MODEL	# OF STEPS	DURATION (h:min)	ENERGY (kWh)	CREW (min)
M01	15	16:59	5.999	30
M22	15	12:49	4.748	30
M10	14	5:12	1.375	18
A26	6	2:10	1.375	30

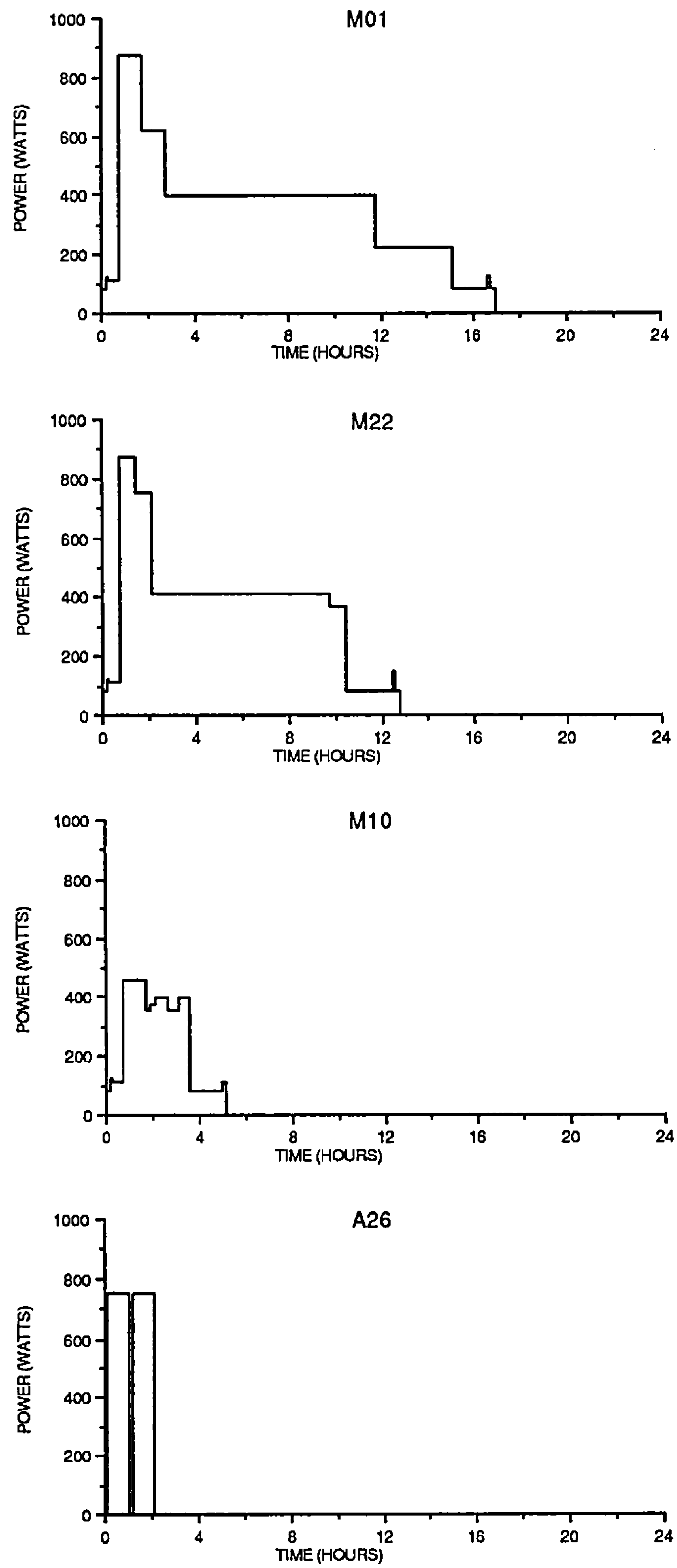


Figure 1. Activity power requirements profiles.

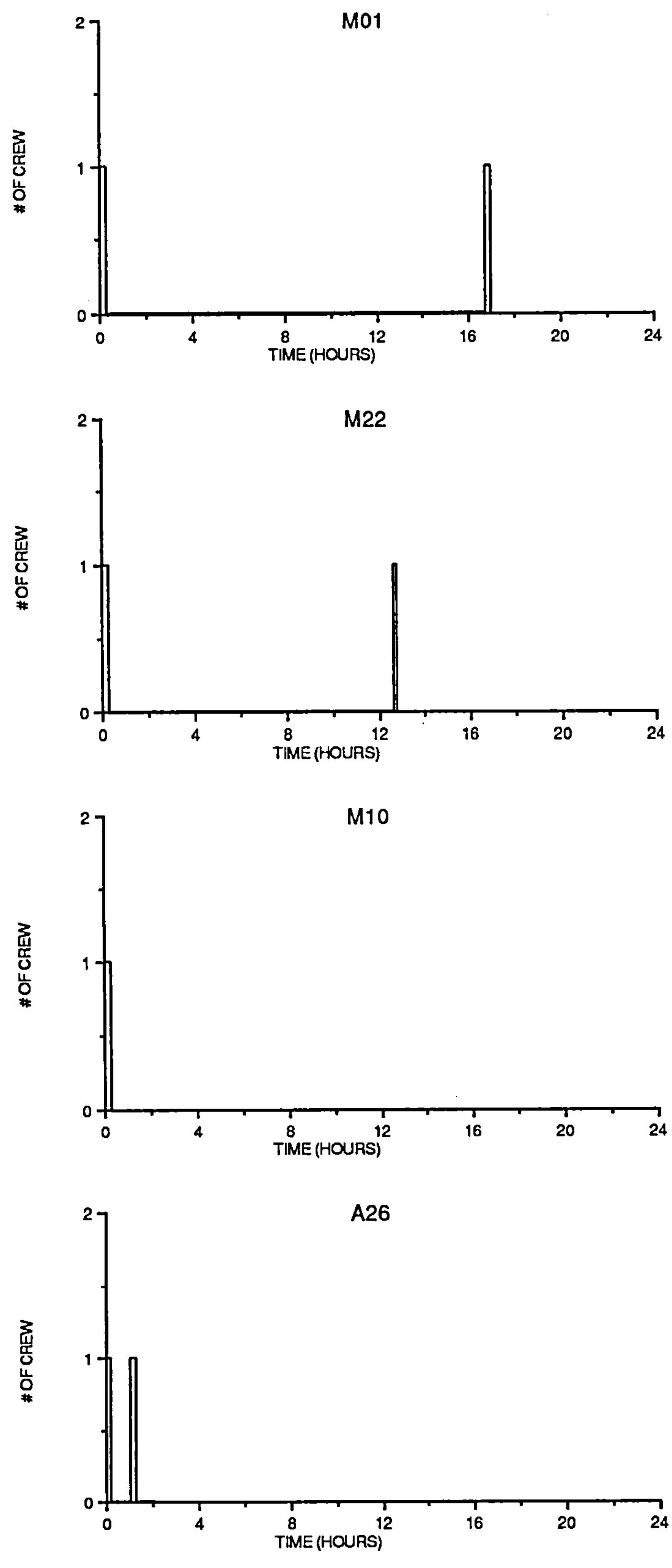


Figure 2. Activity crew requirements profiles.

Seven potential methods for creating payload resource envelopes are presented for analysis and discussion [1,2]. Five of these methods have been assessed against the three reference models M01, M22, and M10. Two of the methods involve models with specific attributes and were assessed using reference model A26. The methods were applied to the respective models, thus creating activity envelopes for power and crew and allowing a comparison of cost and benefits. In practice, an activity envelope would have to be created for each resource required by the activity.

The three activity envelopes were combined to illustrate an experiment envelope. An experiment envelope is often desired to allow the principal investigator (PI) the flexibility to operate any one of a group of activities within the same envelope. This can also ease the scheduling load by reducing the number of items required to be scheduled.

An experiment envelope is created by assuming a common start time and by overlapping one activity envelope on top of another. This results in a composite envelope with the highest magnitude of each resource required during a time increment, by any of the group of activities, to be reserved for the time increment. Experiment envelopes were created for power and crew for the methods illustrated with the three microgravity models. In practice, experiment envelopes must be created for all resources required by the experiment.

In discussion of analysis results, power is referenced in percent margin while crew time is discussed in actual additional time available. While it is illustrative to discuss the power envelope in terms of percent margin, crew time percent margins can be misleading since we are dealing with requirements in minutes; therefore, crew time is discussed as actual increases.

METHOD 1 – APPLICATION OF FIXED LENGTH OF TIME

Method 1—Application of Fixed Length of Time—increases the run time of an activity. For each step within the model, all resources required for that particular step are extended for a fixed amount of time beyond the normal step duration. This effectively allows the activity to operate anywhere within the expanded timeframe. In those instances where an activity model has variable step durations, the maximum step duration will be used as the requirement.

Activity models M01, M22, and M10 have been used to illustrate this method. One hour of additional time has been arbitrarily chosen to add to each activity to define individual activity envelopes for power and crew. Figure 3 depicts the individual activity power envelopes created by adding 1 h of additional run time to each model. The power level for each step in each activity is extended by 1 h beyond the normal step duration.

Crew is made available for 1 h beyond the normal duration of each step requiring crew. The crew envelopes resulting from this method are presented in figure 4. In activities M01 and M22, crew is extended for 1 h for the initiating steps and 1 h for the terminating steps. Crew availability for activity M10 is extended for 1 h for the initiating steps only, since crew is not required on the terminating steps.

In a manner similar to the power and crew resources, all additional required resources must be reserved for 1 h beyond the normal step duration. This allows the 1-h envelope to be used for any step or

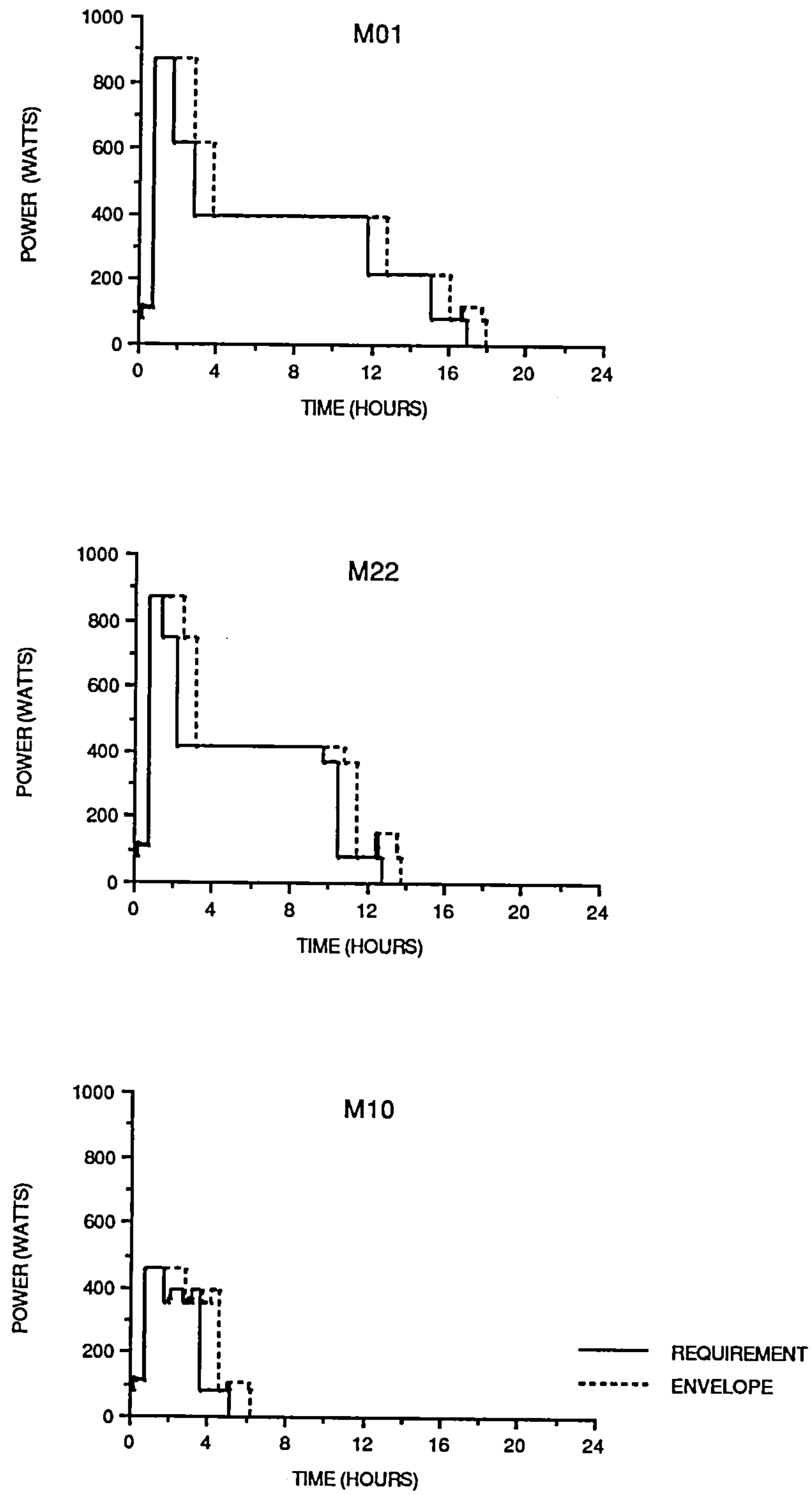


Figure 3. Individual activity power envelopes – Method 1.

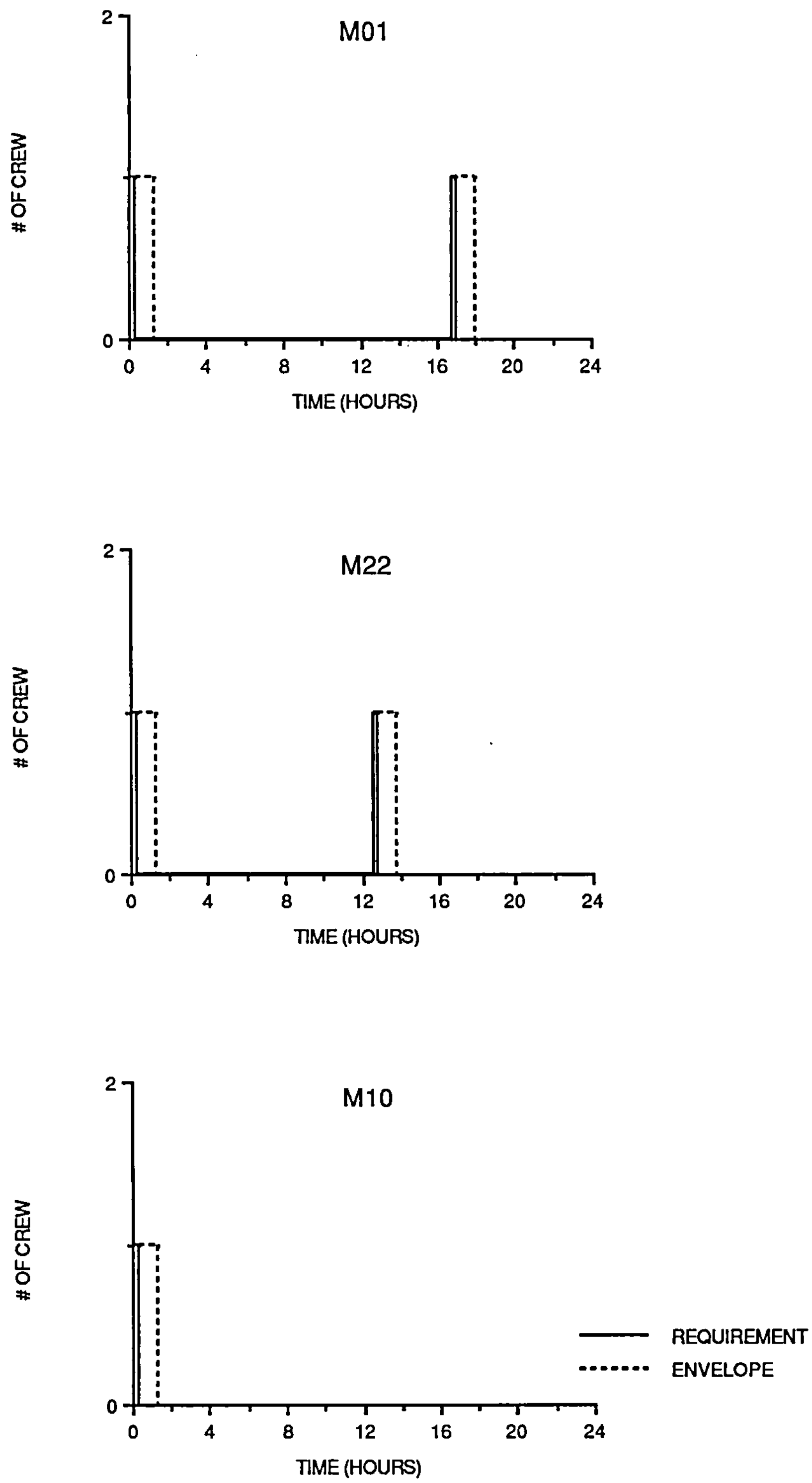


Figure 4. Individual activity crew envelopes – Method 1.

combination of steps. The envelope can be used to delay the startup of the activity or of any steps within the activity. The envelope can also be used to allow a step or combination of steps to operate 1 h longer. The delays and increased step durations will result in an overall increased run time of 1 h or less.

The application of the 1-h envelope to the steps within the activity results in time intervals during which resources from two or more steps must be reserved. The overlapping of resources for activity steps will ensure that the 1-h envelope can be used at any time during the activity performance, and that once a step has been completed, the next step may begin without delay.

The addition of the 1-h envelope increases the amount of resources which must be scheduled for the activity. Figure 5 identifies the percent margin increase in power and the additional crew time resulting from the addition of the 1-h envelope on each of the three models. The resulting percent power margin is 15 percent for the longest duration activity M01, nearly 20 percent for M22, and 37 percent for the shortest duration activity M10. Two hours of additional crew time were added to M01 and M22, 1 h at activity startup and shutdown, while 1 h was added to M10 at startup.

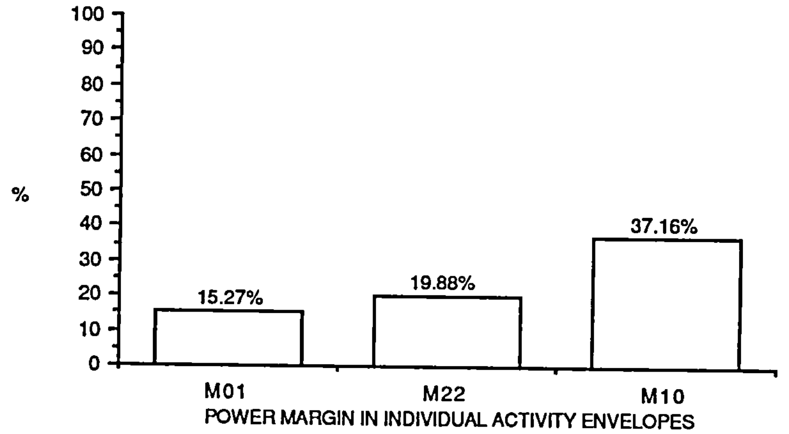
The additional resources required represent the cost of added flexibility in the activity envelope. Since resources are limited, any resources allocated beyond the amount required for an activity effectively prevent other science objectives from being scheduled. The additional resources also reduce the number of performances which can be scheduled for the activity itself.

The amount of energy and crew time which must be scheduled for the original activity models and the models with 1-h added flexibility are compared in table 6. The second column lists the energy consumption for the original models, while the third column lists the consumption for the 1-h method. The difference, listed in the fourth column, is the cost. The cost in energy is 0.916 kWh for M01, 0.944 kWh for M22, and 0.511 kWh for M10.

The crew time required for the original model is provided in the fifth column of table 6. The sixth column lists the crew time required for the 1-h method. The cost in available crew time is listed in the seventh column. The cost is 2 h each for activities M01 and M22, and 1 h for activity M10.

The individual activity envelopes for M01, M22, and M10 were combined to create an experiment envelope for power and crew. This was accomplished by assuming a common start time and superimposing one individual activity envelope profile on top of another to determine the composite experiment envelope profile. The experiment envelope created allows for one run of any one of the three activities plus 1-h flexibility.

The top profile of figure 6 depicts the buildup by superimposing the activity power envelope profiles. The lower profile depicts the resulting composite power profile, which is the experiment power envelope. The composite profile represents the amount of the resource which must be reserved for each performance of any one activity in the experiment. In the example presented, one performance of M01 would use nearly all the reserved power, yet one run of M10 would require only a small amount of the reserved power. The remainder, or margin, is the cost of adding flexibility through the creation of an experiment envelope.



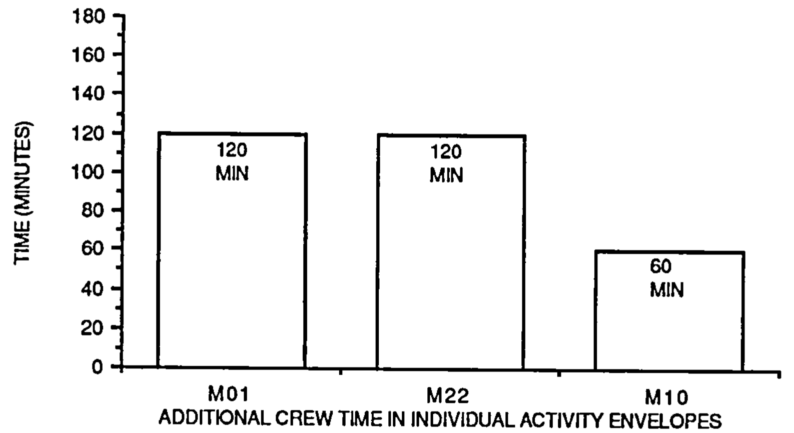


Figure 5. Power and crew resource envelope analysis – Method 1.

Table 6. Comparison of resource usage – original model and Method 1.

MODEL	ORIGINAL ENERGY (kWh)	METHOD 1 ENERGY (kWh)	COST IN ENERGY (kWh)	ORIGINAL CREW (min)	METHOD 1 CREW (min)	COST IN CREW (min)
M01	5.999	6.915	0.916	30	150	120
M22	4.748	5.692	0.944	30	150	120
M10	1.375	1.886	0.511	18	78	60

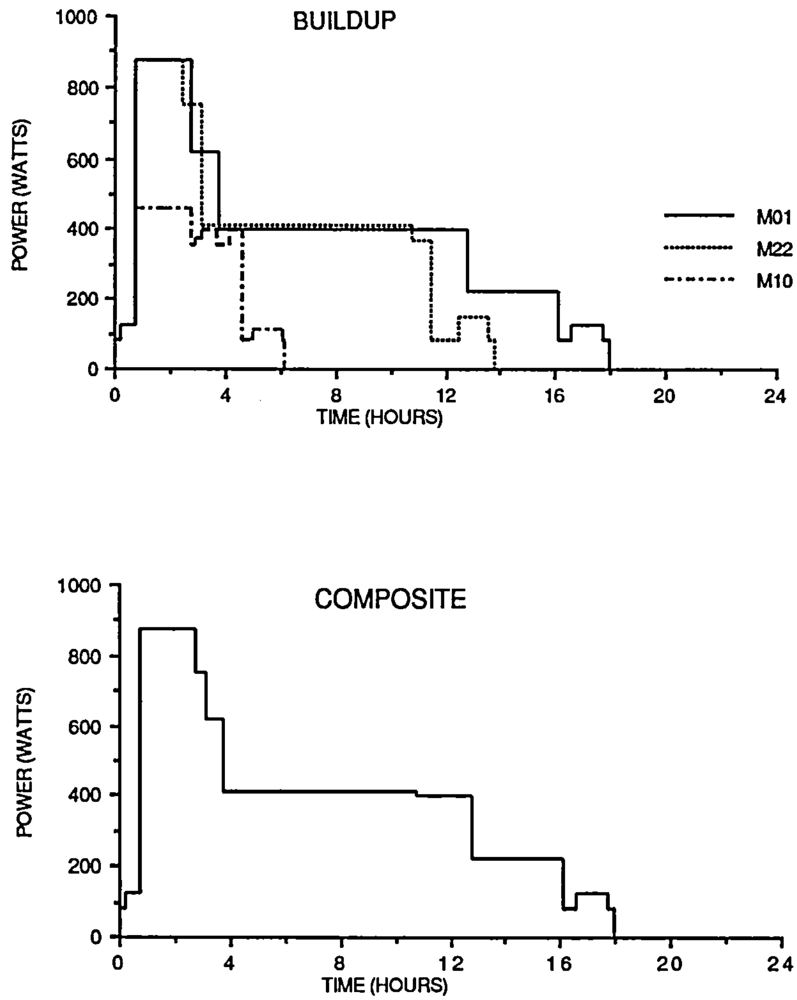


Figure 6. Experiment power envelope – Method 1.

The experiment crew envelope is the composite of the three activity envelope profiles. This is depicted in figure 7. For one run of activity M01, the first and third periods of reserved crew time are utilized. Activity M22 utilizes the first and second reserved crew periods, while activity M10 utilizes only the first reserved period. The remaining scheduled, but unused, crew time represents the cost of the experiment envelope.

The increase in power and crew time resulting from the creation of an experiment envelope is depicted in figure 8. In order to accommodate one run of any one of the individual activities, the experiment envelope will usually contain larger amounts of resources than the individual activity envelopes. The activity with the highest resource usage will have the lowest percentage of increase, while the activity with the lowest resource usage will have the highest increase.

In the example presented, for activity M01 there is an increase of 17 percent in the amount of power reserved in the experiment envelope over that reserved in the individual activity envelope. The experiment envelope incorporates nearly a 49-percent increase in power over the amount reserved for the individual activity envelope for M22 and 413 percent for M10. Referring to the top profile of figure 6, it can be seen that one performance of activity M10 would leave a large portion of the reserved power unused.

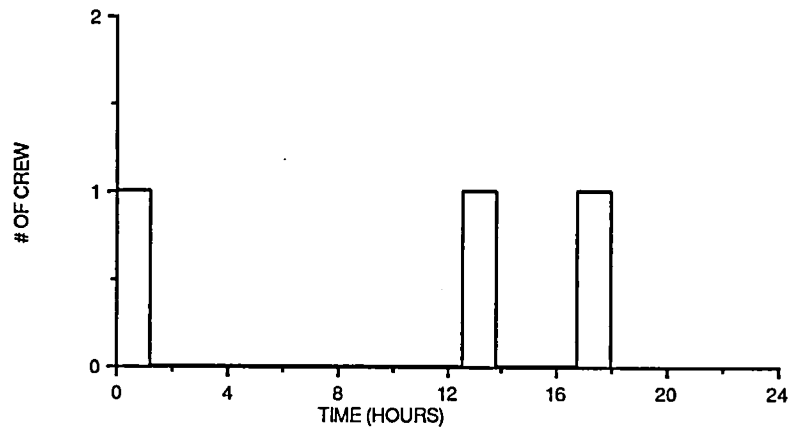


Figure 7. Experiment crew envelope – Method 1.

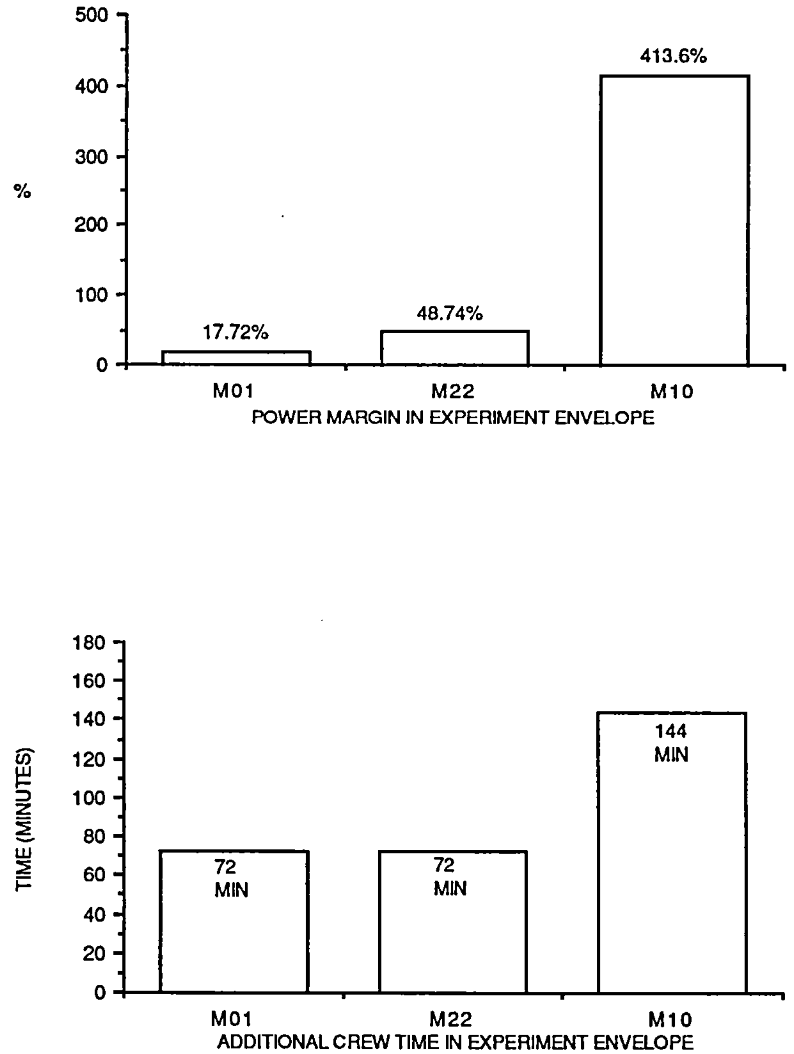


Figure 8. Experiment resource envelope analysis – Method 1.

Total crew time in the experiment envelope is 222 min. The individual activity envelopes for M01 and M22 require 150 min each. This results in an additional 72 min of crew time in the experiment envelope over that in the activity envelopes for each of the activities. The experiment envelope contains an additional 144 min beyond the 78 min in the activity envelope for M10.

An experiment envelope must be created for each resource required by the activities. The margins in power and crew, as well as in other resources, represent the cost of the experiment envelope in that these resources would not be available for scheduling other experiments. Adjustments can often be made to the envelope to reduce its cost. In the example presented, a slight increase in the power experiment envelope would allow for a second performance of the shortest duration activity (M10), thereby reducing the potential waste of resources.

Smoothing of resource profiles is often desirable to simplify modeling and scheduling as well as to provide added flexibility. The number of steps in an activity or an experiment can sometimes be reduced by combining similar consecutive steps. In doing so, the combined step is allocated the highest magnitude of each resource required for the steps being consolidated. This results in activities with fewer steps and therefore smoother resource profiles.

Smoothing the beginning and end of the experiment power envelope is illustrated in figure 9. This smoothing, which was performed in an arbitrary manner, results in a 3.2-percent increase in energy consumption.

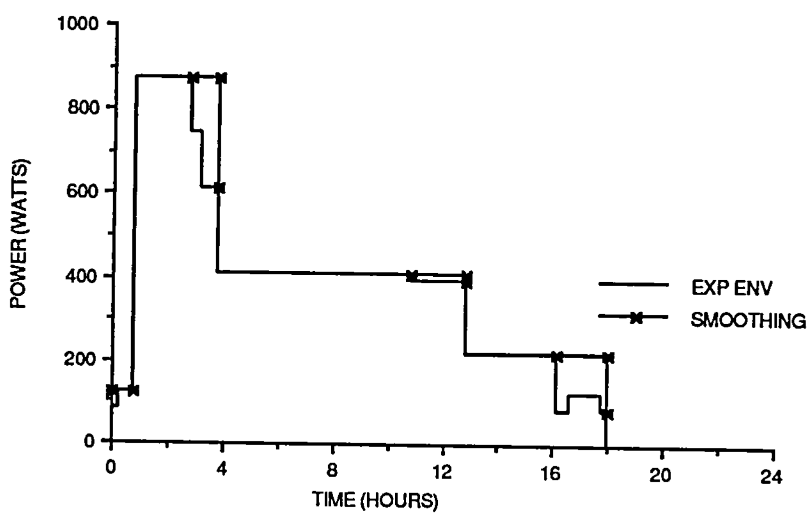


Figure 9. Smoothing experiment power envelope – Method 1.

Summary

Method 1 activity envelopes allow for one run of the specific activity plus a fixed length flexibility in run time. The example utilized 1 h, however, this could be varied to allow more or less flexibility as necessary. The 1-h increase in run time resulted in a very small increase in the energy required to be reserved for each of the activities. Two hours of additional crew time were required for both activities M01 and M22. One hour of additional crew time was necessary for activity M10.

The experiment envelope created would allow for one run of any one of the three activities plus the 1-h flexibility. One performance of activity M01 in the experiment envelope results in a small amount of unused energy, while more than 1 h of crew time remains unused. A performance of M22 in the experiment envelope would leave nearly 50 percent of the reserved energy unused. Unused crew time is equal to that of a performance of M01. Since activity M10 is the shortest in duration and requires crew only in the initiating steps, a large amount of the resources reserved would remain unused by its performance. As was previously mentioned, a slight increase in resources would allow a second M10 performance within the envelope, thereby reducing costs.

Method 1 allows the added time to be utilized at any time during the activity envelope without causing delays between steps. The method provides an equal fixed distribution of resource envelope, however, when large differences exist in activity run times, this may not be operationally sound. For example, 1-h flexibility may be adequate for a 6- to 10-h activity, but inadequate for a 15- to 20-h activity. The fixed length of time could vary according to the duration of the activity. This method could be modified to allow for other factors such as resource profile smoothing and maximum utilization of the experiment envelope.

METHOD 2 – VARIABLE ACTIVITY DURATIONS

Method 2—Variable Activity Durations—considers only those activities which have steps with variable durations. Variable step durations may be desired to accommodate operational factors (in-flight learning, experience), scientific factors (furnace time as a function of sample, observation opportunities), or to allow in-fight flexibility for contingencies. The proposed method would use the minimum step duration as the requirement and the maximum step duration as the envelope. All resources required for steps with variable duration would be extended for the maximum step duration.

Activity A26 has been used to illustrate this method. As can be noted from table 4, steps 3 and 6 have a variable duration of 50 to 65 min. These two steps require 750 W/h and no crew usage. To incorporate flexibility into the activity, steps 3 and 6 are scheduled for 65 min.

The power profiles for this method are depicted in figure 10. The minimum duration of 50 min is used as the requirement (top profile of figure), and the maximum duration of 65 min is used as the envelope (lower profile of figure). This results in an increase of 30-min run time for the activity.

Crew is not required during the steps involving variable durations so there is no increase in the amount of crew usage. This is a shift, however, in the time at which crew is required for steps 4 and 5 since these steps now occur 15 min later. Figure 11 depicts the crew profiles for the requirement and the envelope for the entire activity duration. The periods of zero crew usage on the graphs represent steps 3 and 6.

The percent margin increase in power and crew time resulting from the addition of the envelope is identified in figure 12. The amount of power required to be reserved increases 27 percent. Crew time remains the same as in the original crew profile.

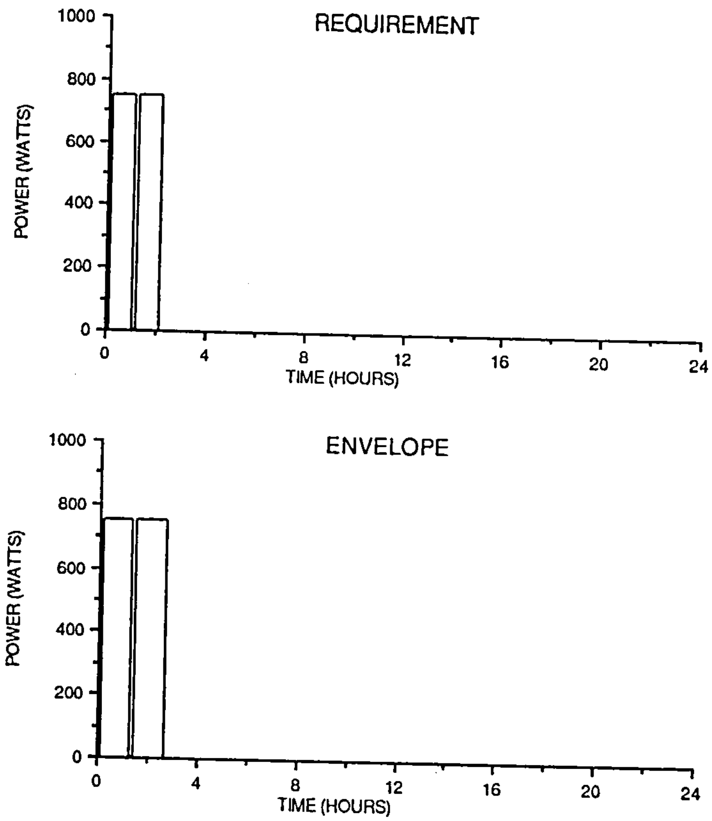


Figure 10. Activity A26 power profiles – Method 2.

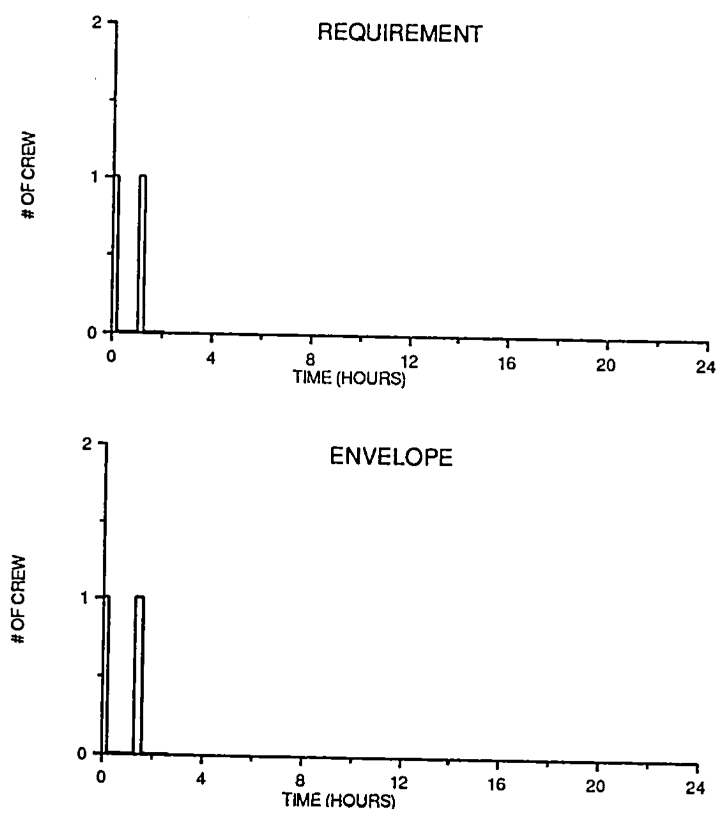
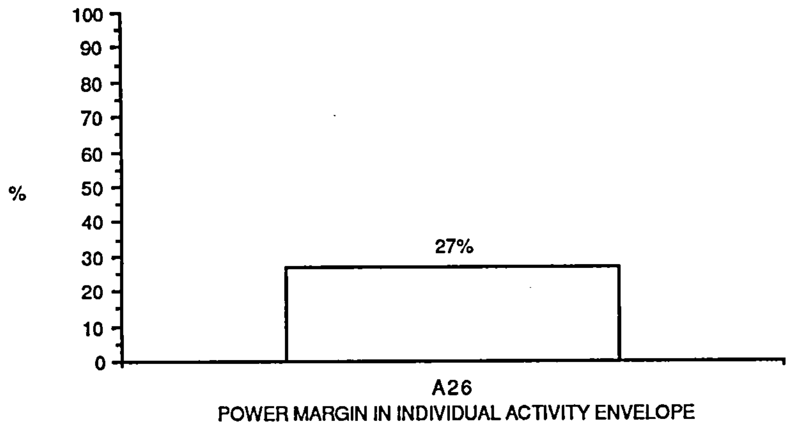


Figure 11. Activity A26 crew profiles – Method 2.



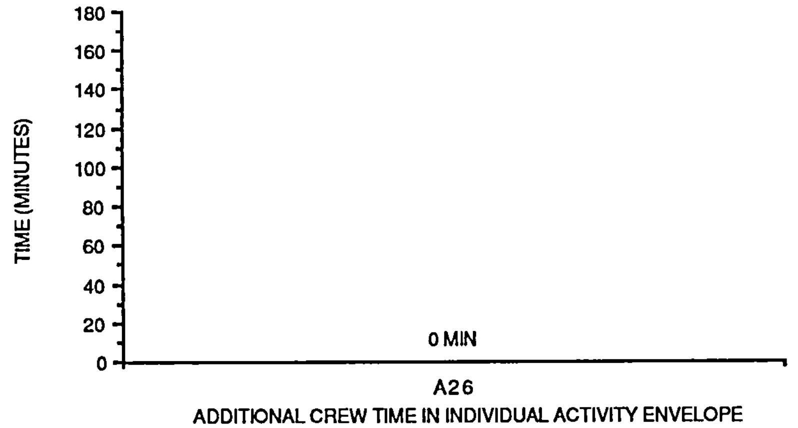


Figure 12. Power and crew resource envelope analysis – Method 2.

A comparison of the resource consumption for the original activity and Method 2 is provided by table 7. The amount of energy required for the original schedule is listed in the second column. The third column lists the amount of energy required with the application of Method 2. The cost in energy, 0.375 kWh, is the difference between the second and third columns. The fifth and sixth columns list the crew required for the original schedule and Method 2. As indicated in the seventh column, there is no cost in crew for this particular activity.

This method is illustrated with a single activity experiment, therefore, the experiment envelope would be identical to the activity envelope.

Table 7. Comparison of resource usage – original model and Method 2.

MODEL	ORIGINAL ENERGY (kWh)	METHOD 2 ENERGY (kWh)	COST IN ENERGY (kWh)	ORIGINAL CREW (min)	METHOD 2 CREW (min)	COST IN CREW (min)
A26	1.375	1.750	0.375	30	30	0

Summary

Method 2—Variable Activity Duration—adds flexibility to an activity by extending the duration of the variable steps to the maximum duration. Only those steps with variable duration are provided the added flexibility.

In the example presented, the window for performance of the activity is extended by 30 min with only a small increase in energy and no increase in crew. The cost of added flexibility, in general, is dependent upon the attributes of the particular activity model.

The method, as presented here, requires a delay between steps if the full step duration is not utilized by the step activity. Additional resources could be applied, in the manner discussed in Method 1, to allow follow-on steps to begin immediately upon completion of the predecessor step.

This method is applicable only to a specific class of experiments, those with variable step durations. For models whose critical steps are of variable duration, such as observation opportunities, this method conserves resources by applying flexibility only where it is most needed.

METHOD 3 – APPLICATION OF FIXED PERCENTAGE OF TIME

Method 3—Application of Fixed Percentage of Time—increases the individual activity step duration by a fixed percentage. For each step within the model, all resources required for that particular step are extended for a fixed percentage of time beyond the normal step duration. If the step has a variable duration, the maximum is used as the requirement. The effect of the envelope is cumulative which allows each step to run the fixed percentage of time beyond its normal duration. Completion of an activity step in less time than the step duration with margin will result in a delay for the remainder of the step duration.

An additional 25 percent of each step's time has been arbitrarily chosen to create individual activity envelopes for power and crew using activities M01, M22, and M10. The duration of each step, along with its required resources, was increased to allow a 25-percent flexibilty factor.

The individual activity power envelopes are depicted in figure 13. The envelope increases the run time of each step by 25 percent, thereby delaying the start of the follow-on step. Referring to the graphs, the start of each step is no longer as indicated by the requirement but is the end of the previous envelope.

The crew envelopes are illustrated in figure 14. As can be noted from the graphs, the percent increase for each step causes a shift in the time crew is required for terminating steps as well as extending the amount of crew time required.

The percent margin increase in power and the additional crew time resulting from application of this method are identified in figure 15. The additional amount of power required is 25 percent for all models. Crew time is increased 4.5 min for M10 and 7.5 min for M01 and M22.

The comparison of the original energy and crew usage requirements with the resources necessary to implement the 25-percent increase in step duration is indicated in table 8. The second column lists the

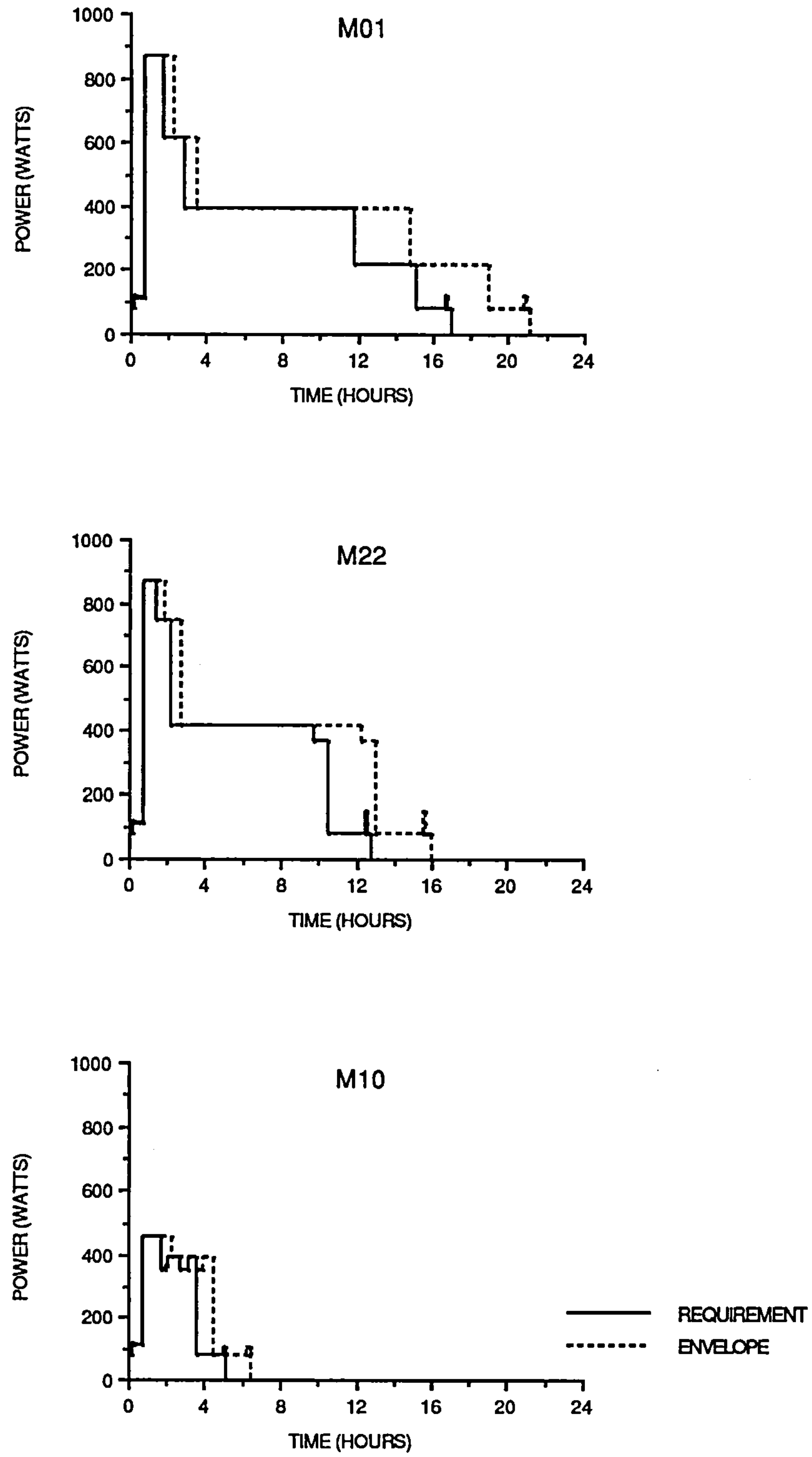


Figure 13. Individual activity power envelopes – Method 3.

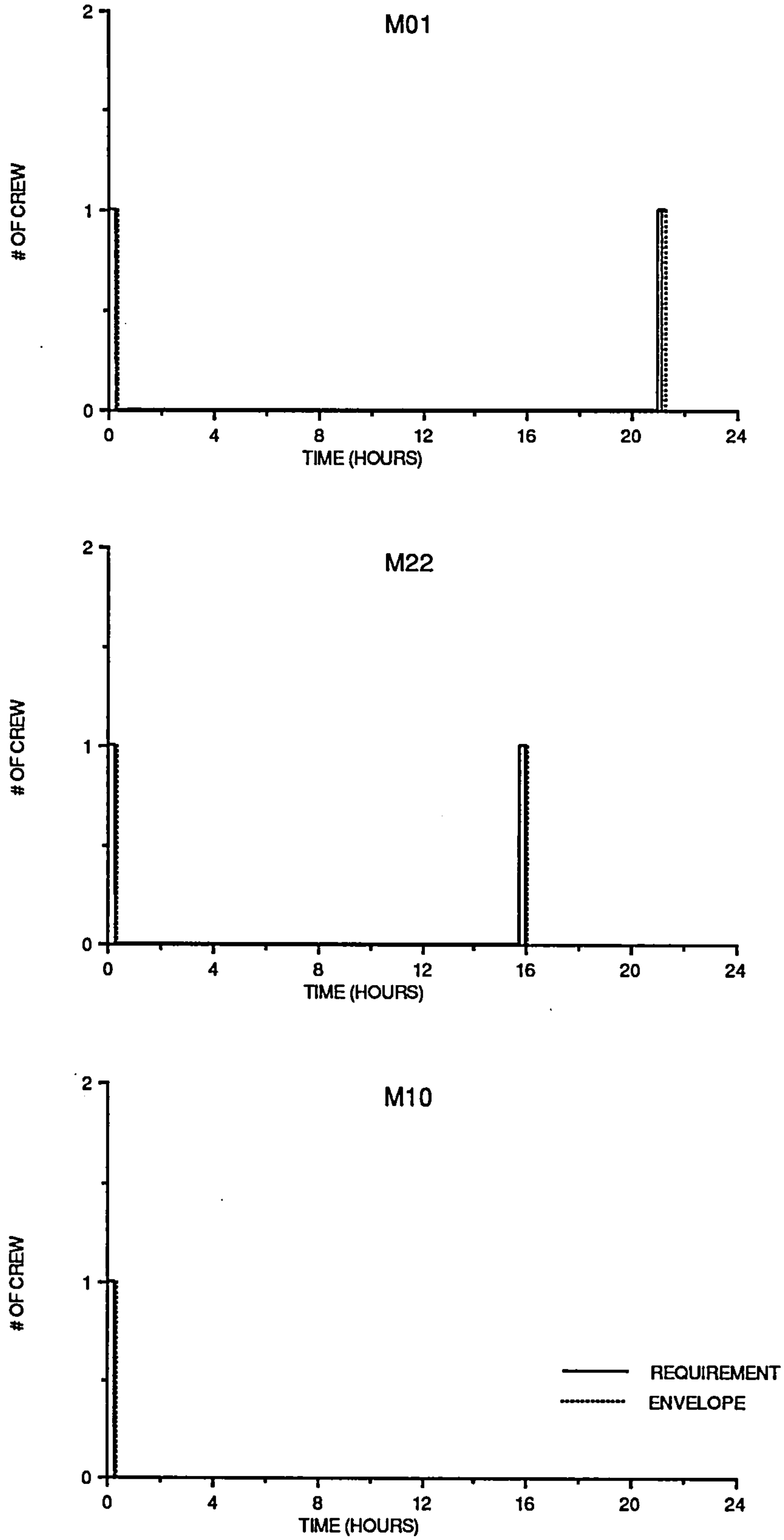
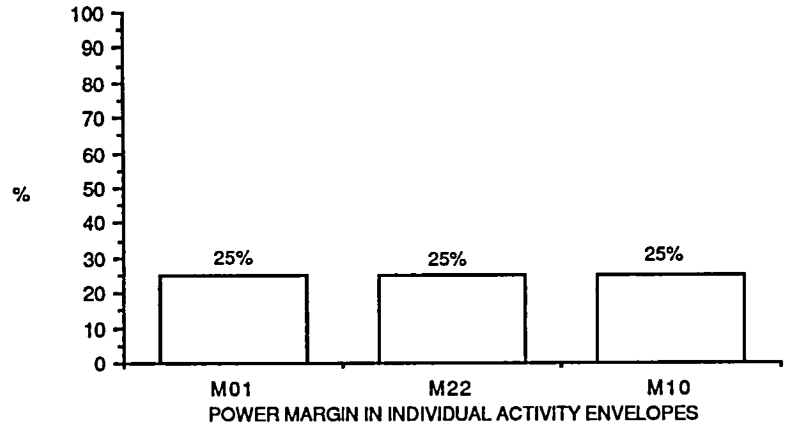


Figure 14. Individual activity crew envelopes – Method 3.



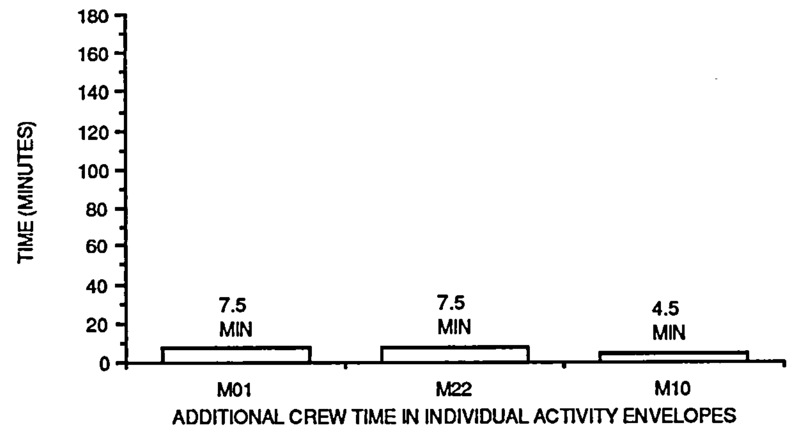


Figure 15. Power and crew resource envelope analysis – Method 3.

energy required for the original activity, while the third column lists the amount required for the envelope. The cost in energy is listed in the fourth column. Activity M01 has a cost of 1.499 kWh, while M22 has a cost of 1.188 kWh and M10 has a cost of 0.332 kWh.

The fifth and sixth columns of table 8 list the crew time for the original activity and envelope, respectively. The seventh column lists the cost in crew time as 7.5 min for models M01 and M22 and 4.5 min for M10.

An experiment envelope has been created by combining the individual activity envelopes for M01, M22, and M10. The buildup of the three individual activity power envelope profiles and the resulting experiment power envelope profile are presented in figure 16. The experiment crew envelope resulting from the buildup of the three individual crew activity envelopes is presented in figure 17. A resource envelope must be created for each resource required by any of the three activities. The experiment envelope allows for one run of any one of the three individual activities.

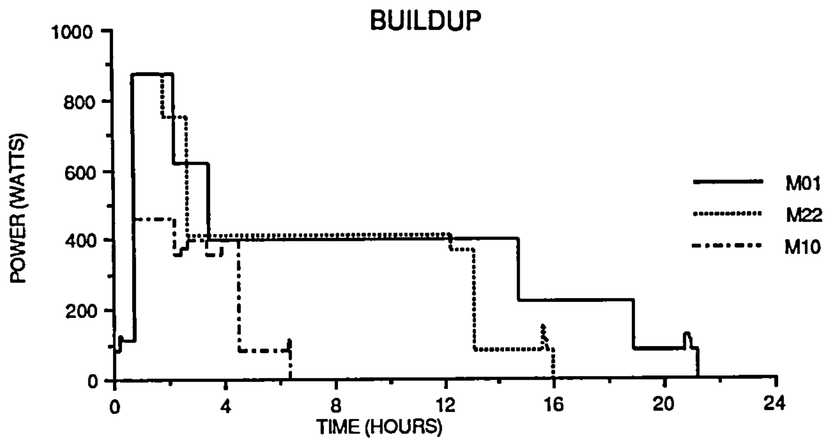
The increase in power and crew resulting from the creation of the experiment envelope is depicted in figure 18. These margins represent the additional resources which must be reserved for the experiment envelope beyond the amount necessary for the individual activity envelopes. The percent power margins for individual activities within the experiment envelope are 28 percent for M01, 62 percent for M22, and 459 percent for M10. Additional crew time in the experiment envelope ranges from 15 min for M01 and M22 to 30 min for M10.

The effect of smoothing the beginning and end of the experiment power envelope, to add flexibility and facilitate ease of scheduling, is illustrated in figure 19. This arbitrary smoothing results in an increase of 4.9 percent in the power envelope.

Method 3 requires the prescribed step duration, including the flexiblity factor, to expire before the next step may begin. For the example under examination, the following are the expansions in run time resulting from this method: M01, 254 min; M22, 192 min; and M10, 78 min. The magnitude of start time flexibility is dependent on the initiating step's duration. The initiating steps for M01, M10, and M22 have 1.25-min additional run time since they are of 5-min duration. Therefore, these activities can start 1.25 min late or the initiating step can run 1.25 min longer. This method can be modified to increase the flexibility of the initiating steps.

Table 8. Comparison of resource usage – original model and Method 3.

MODEL	ORIGINAL ENERGY (kWh)	METHOD 3 ENERGY (kWh)	COST IN ENERGY (kWh)	ORIGINAL CREW (min)	METHOD 3 CREW (min)	COST IN CREW (min)
M01	5.999	7.498	1.449	30	37.5	7.5
M22	4.748	5.936	1.188	30	37.5	7.5
M10	1.375	1.707	0.332	18	22.5	4.5



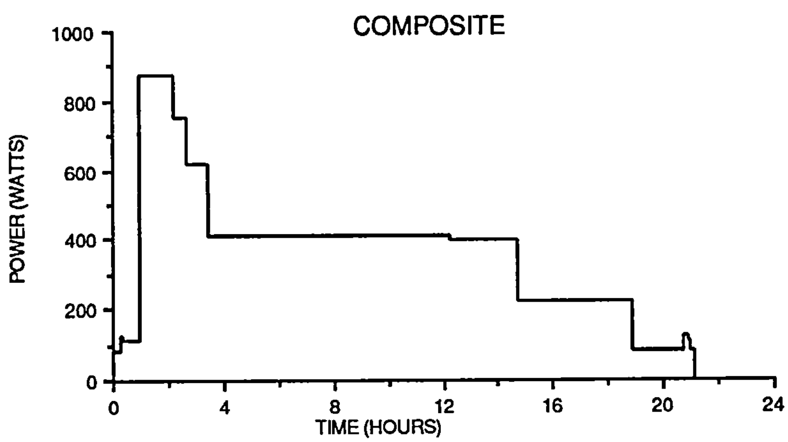


Figure 16. Experiment power envelope – Method 3.

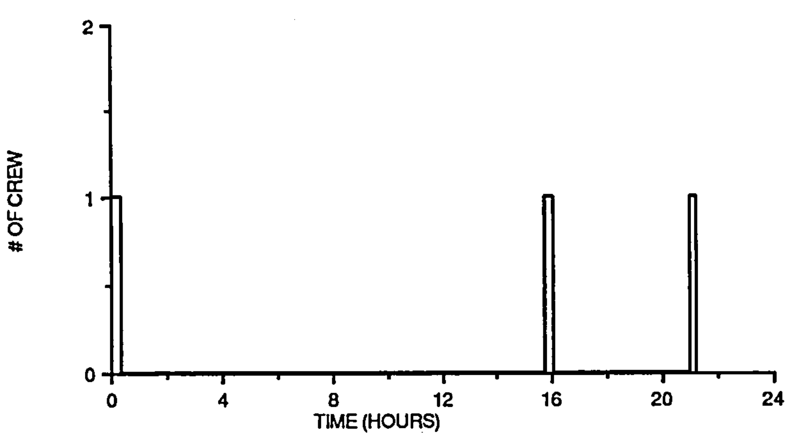
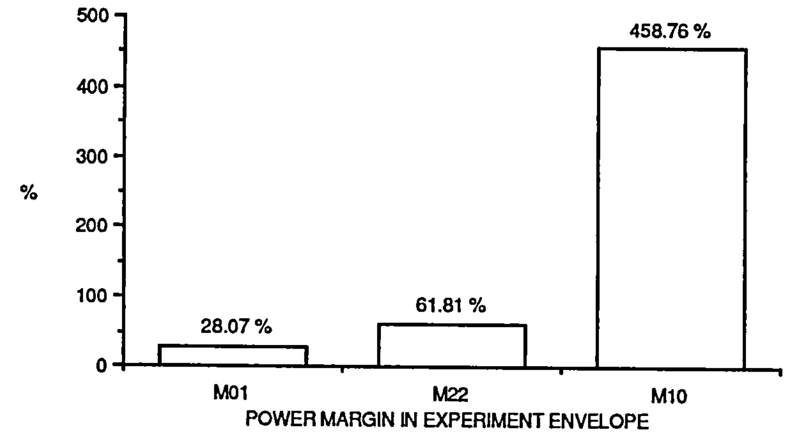


Figure 17. Experiment crew envelope – Method 3.



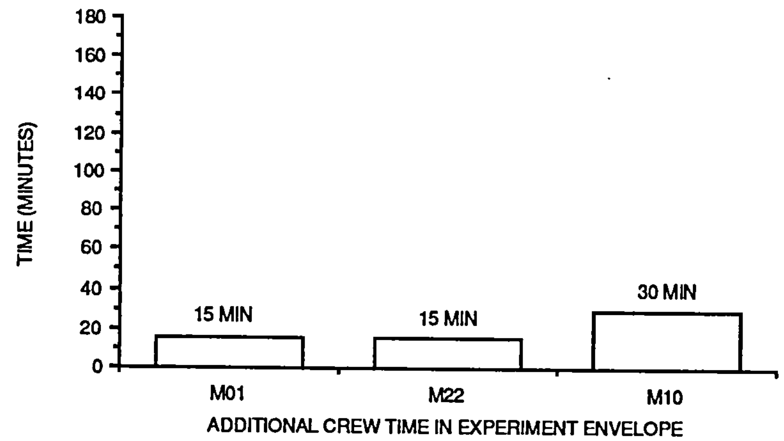


Figure 18. Experiment resource envelope analysis – Method 3.

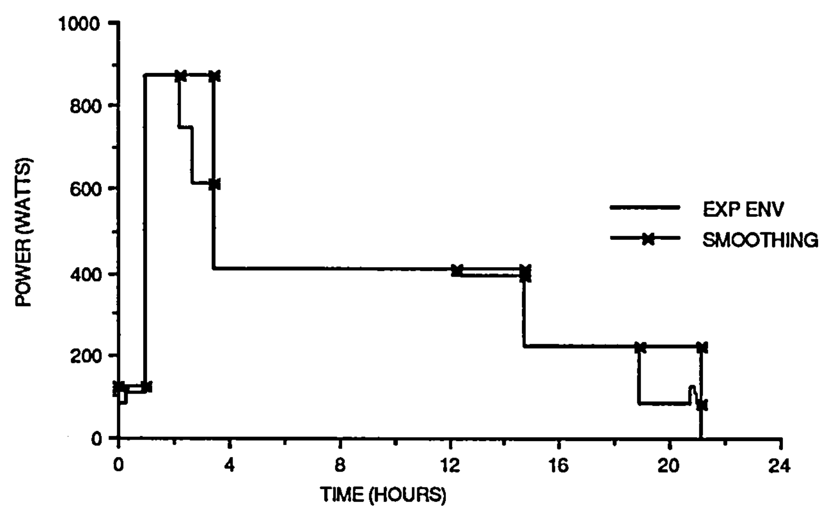


Figure 19. Smoothing experiment power envelope – Method 3.

Summary

Method 3—Application of Fixed Percentage of Time—adds flexibility by increasing the run time of each step in the activity by a fixed percentage. The examples presented herein used 25 percent as the increase, though this could be adjusted to allow more or less flexibility as desired.

The application of the method to the activities herein resulted in small increases in power and crew for the activity envelopes. In the experiment envelope, there was an increase of 15 to 30 min in crew time and 28 to 460 percent for power. Adjustments to the experiment envelope would allow an additional M10 run, thereby reducing costs.

Method 3 requires a delay between steps when the step operation does not fill the entire expanded duration. The method could be modified to avoid the delay by overlapping step resources as in Method 1.

The application of fixed-percentage increases in step duration allows consistent equitable application of flexibility. Depending on the specific activity, more or less flexibility may be desired on certain steps. The method could be easily modified to provide a different (higher) percentage of flexibility for activation and deactivation steps. The method appears best suited for those activities with uncertainty dispersed throughout individual steps.

METHOD 4 – AVERAGE OBSERVATION OPPORTUNITY

Method 4—Average Observation Opportunity—is applicable only to those experiments which require observation periods. This can relate to objects in space such as stars or specific areas on Earth or in the atmosphere. Observation opportunities are often of variable duration across a fixed period of time. This method increases the duration of the step requiring the observation to equal an average pass duration of that specific opportunity. An average pass is defined as the average amount of time the object under study is available for observation.

As an example, steps 3 and 6 of activity A26 (refer to table 4) require observation opportunities. The minimum step duration of 50 min is used as the requirement while the duration of an average pass is used as the envelope. For illustration, an average pass is assumed to be 60 min. For this particular activity, run time is increased 10 min for each variable step for a total of 20 min.

The power profiles for the requirement and envelope are depicted in figure 20. Since a power level of 750 W/h is required for an additional 20 min, the resulting increase in energy usage is 250 Wh.

Crew time is not increased since crew is not required for steps 3 and 6. The time crew is required for steps 4 and 5 is shifted since these steps now occur 10 min later. The crew profiles for the requirement and envelope are illustrated in figure 21.

The percent margin increase in power and crew time resulting from the addition of the envelope is identified in figure 22. Power increases 18 percent while crew time remains the same. The increase in power represents the cost of the activity envelope.

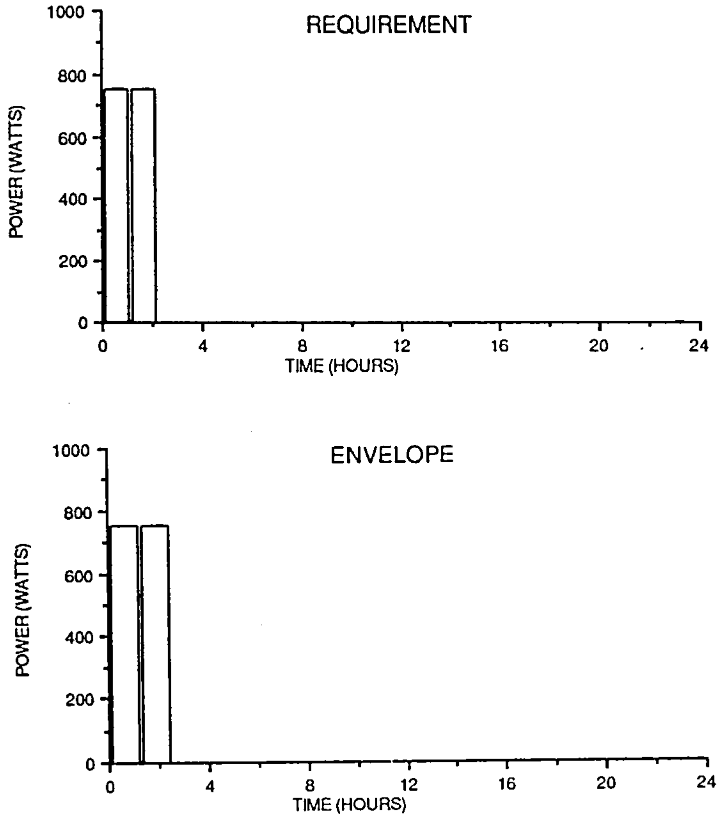


Figure 20. Activity A26 power profiles – Method 4.

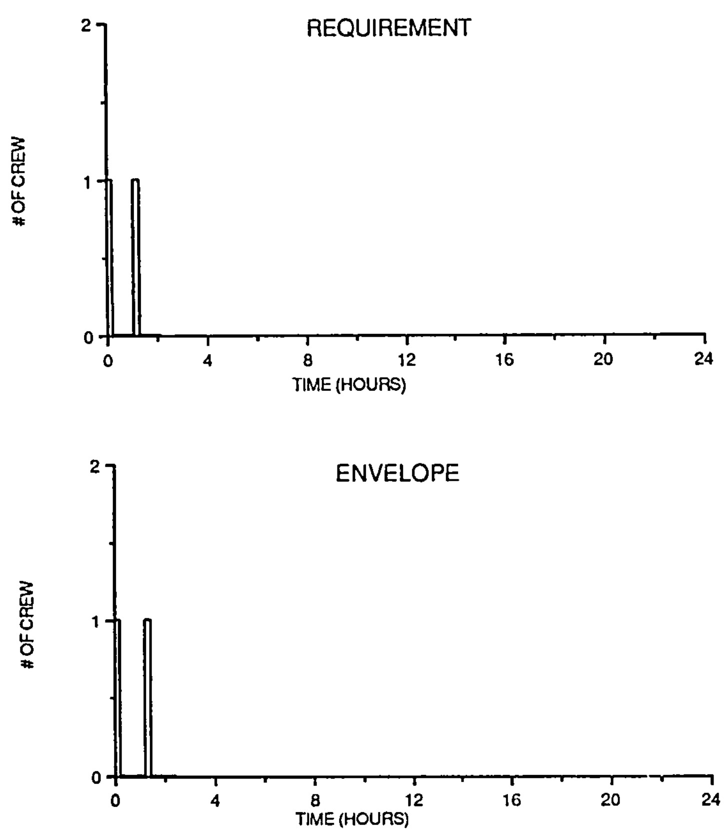
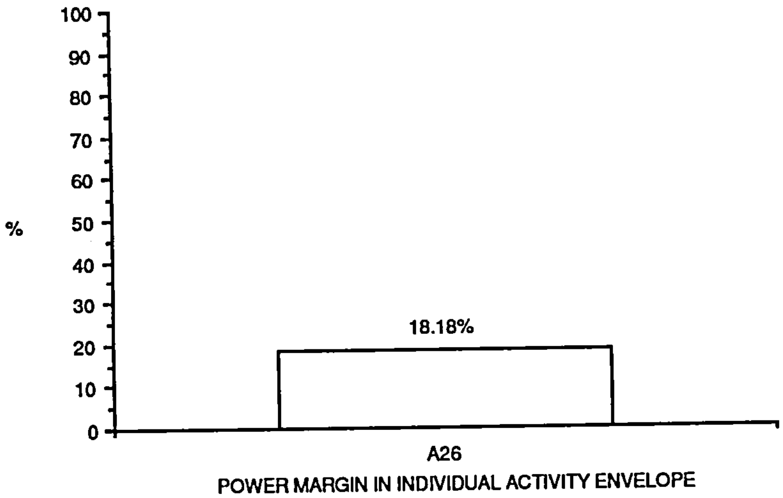


Figure 21. Activity A26 crew profiles – Method 4.



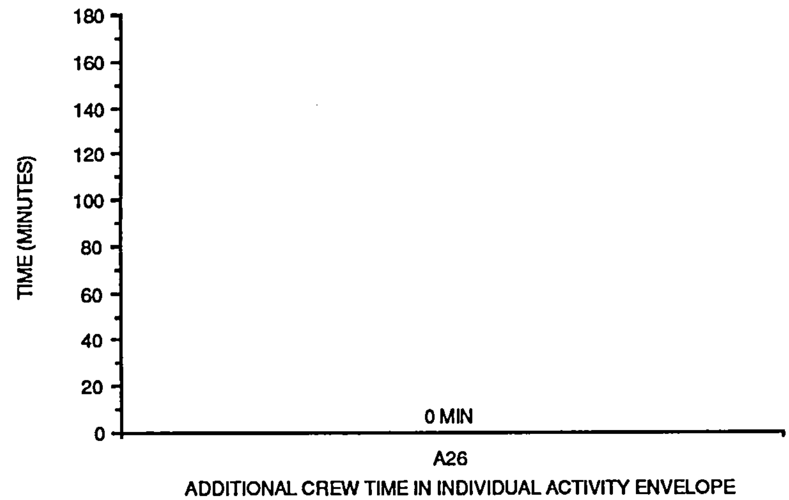


Figure 22. Power and crew resource envelope analysis – Method 4.

A comparison of the original energy consumption and crew usage with that of Method 4 is provided in table 9. The fourth column shows the cost in energy to be 0.25 kWh. The seventh column shows the cost in crew to be zero.

Since this method is addressed with a single activity experiment, the experiment envelope is identical.

Table 9. Comparison of resource usage – original model and Method 4.

MODEL	ORIGINAL ENERGY (kWh)	METHOD 4 ENERGY (kWh)	COST IN ENERGY (kWh)	ORIGINAL CREW (min)	METHOD 4 CREW (min)	COST IN CREW (min)
A26	1.375	1.625	0.250	30	30	0

Summary

Method 4—Average Observation Opportunity—adds flexibility to models requiring observation periods, by increasing the duration of steps requiring the opportunity to equal an average pass of that opportunity. Only those steps requiring an observation are afforded flexibility.

In the example presented, a 20-min increase in the activity performance window is allocated with a very small increase in energy and no increase in crew. The amount of increase in run time and resources is dependent upon the average duration of the pass.

This method could be especially beneficial in the early stages of scheduling when the orbit ephemeris is not well defined or when there may be perturbations after the timeline has been established.

Method 4 is applicable to only those activities which require observation opportunities. The method conserves resources by providing flexibility to only those steps requiring an observation opportunity.

METHOD 5 – INCREASE CONSTRAINING RESOURCE BY FIXED PERCENTAGE

Method 5—Increase Constraining Resource by Fixed Percentage—applies a fixed percentage to a designated constraining resource by increasing the area of the resource profile. This is accomplished by applying portions of the additional resource to increase the run time of steps within the activity in the most beneficial manner. The additional resources necessary to operate the activity during this expanded timeframe must also be made available.

To illustrate this method, power is utilized as the constraining resource, and an arbitrary designation of 50 percent is used as the increase in the power profile (run time only, not magnitude). The amount of energy required by the entire activity is calculated, and an additional 50 percent is allotted to the activity. This additional amount of the resource is applied to individual activity steps, as needed, by increasing run time. Resource envelopes are created for all other required resources by extending these resources to match the run time of steps in the power profile. This method does not increase the run time of the individual steps by the fixed percentage, as in Method 3. Rather, the additional resources available are used to increase the activity steps in the manner deemed most beneficial to the particular activity.

The individual activity power envelopes resulting from the application of the additional power are depicted in figure 23. An additional 50 percent of the amount of power required by the activity has been used to increase the run time of various steps, thereby adding flexibility.

The crew envelopes for this method are presented in figure 24. Crew must be available for the run time of steps as defined by the power profile, resulting in large increases in this resource.

The percent margin increase in power for each activity and the additional crew time resulting from this method are identified in figure 25. The percent power margin is 50 percent by definition of the example case. The crew time, meanwhile, is increased 1.5 h for M10, 5.8 h for M22, and 6.8 h for M01. This method provides 3.4 h added run time for M01, 2.9 h for M22, and 1.5 h for M10.

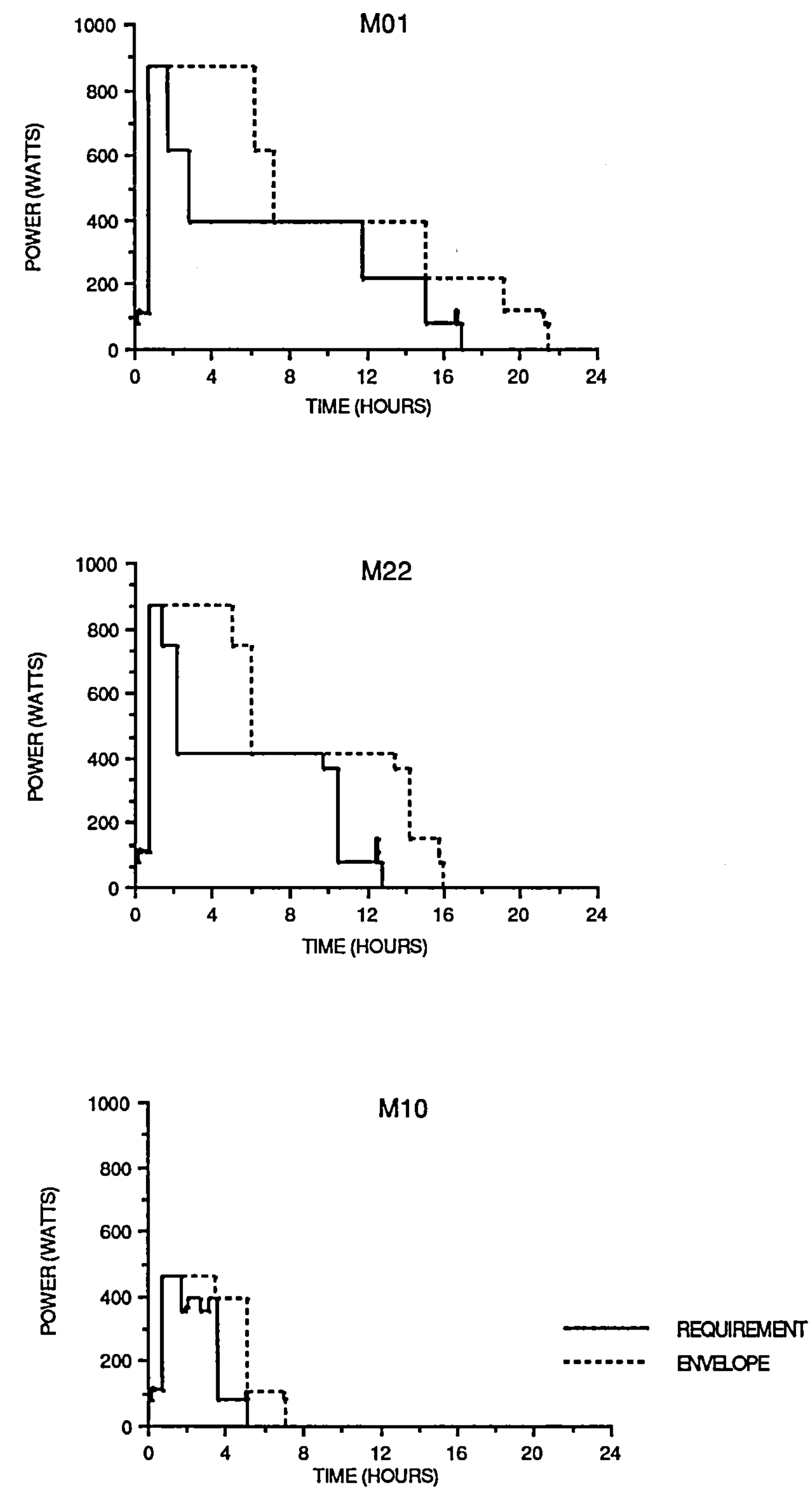


Figure 23. Individual activity power envelopes – Method 5.

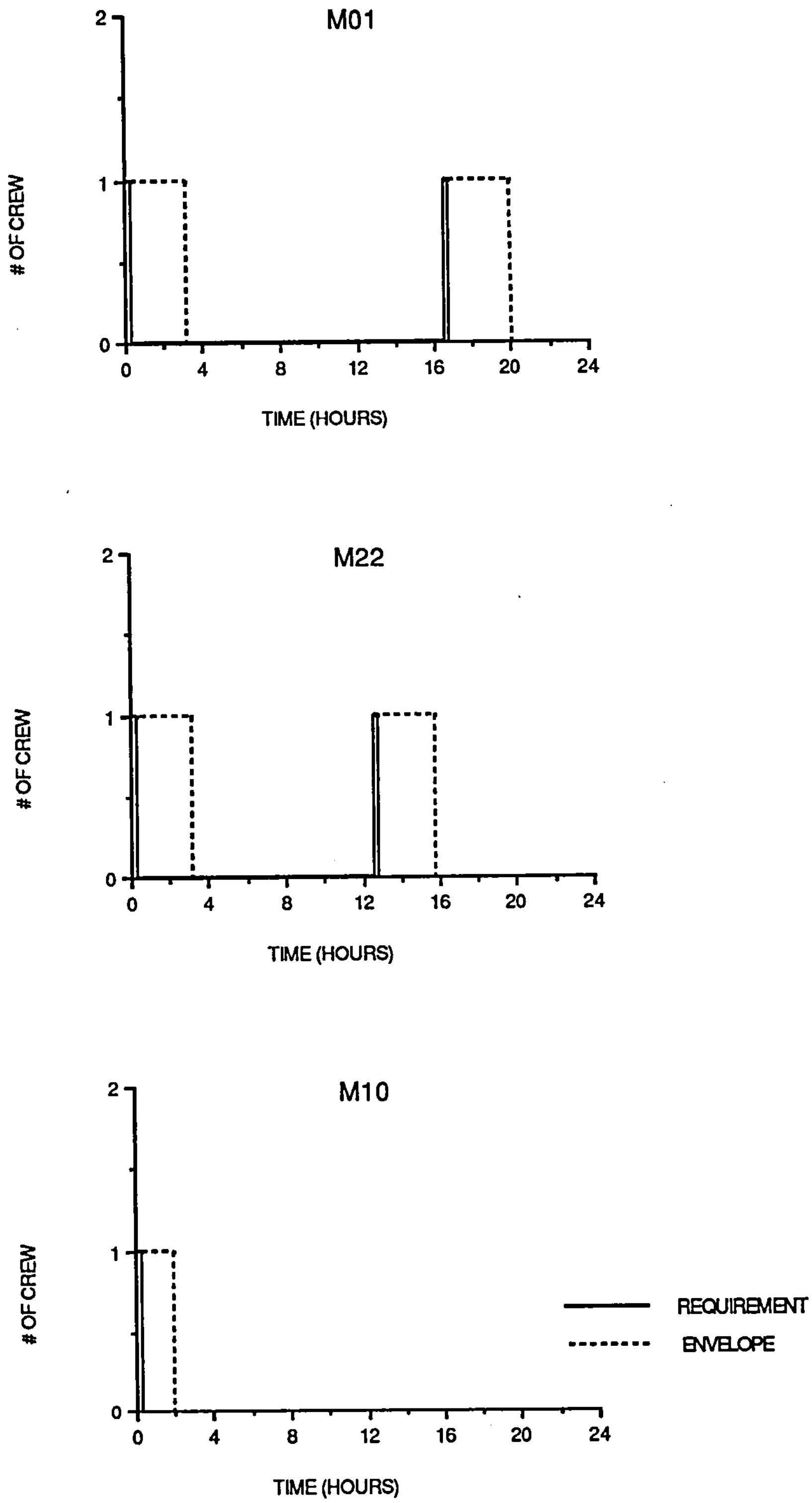
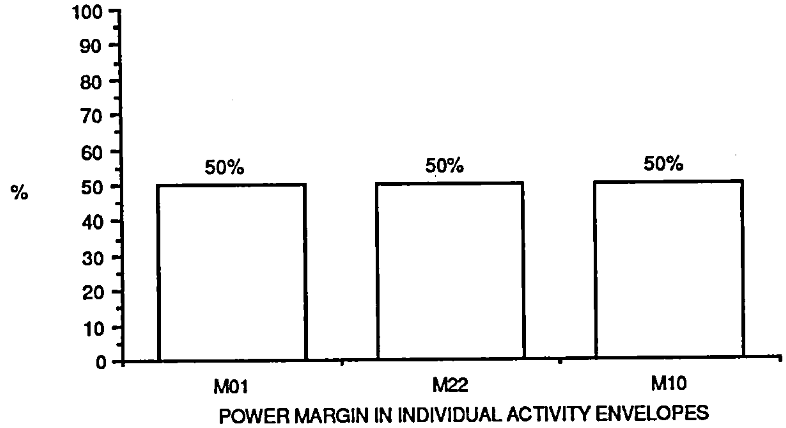


Figure 24. Individual activity crew envelopes – Method 5.



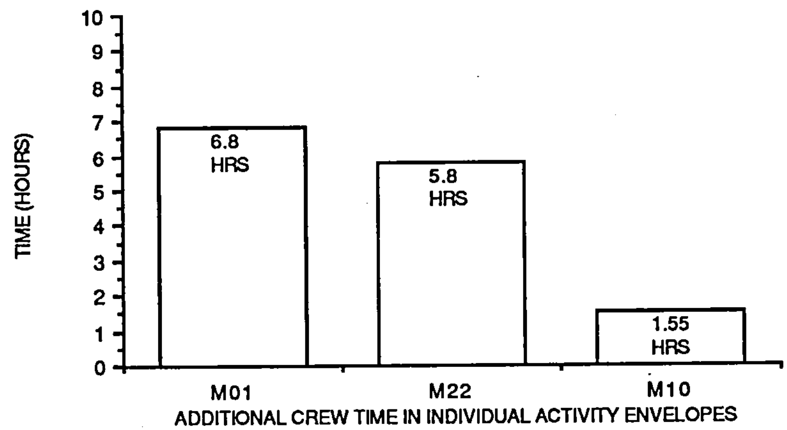


Figure 25. Power and crew resource envelope analysis – Method 5.

The original energy and crew usage requirements were compared with the resources necessary to implement Method 5. The results are listed in table 10. The second column lists the energy consumed by the original activity requirement, while the third column lists the amount of energy required for Method 5. The fourth column lists a cost in energy of 2.999 kWh for M01, 2.374 kWh for M22, and 0.688 kWh for M10.

The crew time utilized by the original activity is presented in the fifth colum of table 10. The sixth column lists the crew time which must be made available by method 5. The seventh column lists the cost in crew as 6.8 h for M01, 5.8 h for M22, and 1.55 h for M10.

An experiment envelope has been created for activities M01, M22, and M10 for power and crew. The envelope provides resources for one performance of any one of the three activities. The top profile of figure 26 illustrates the buildup of the three individual activity power envelopes. The lower profile illustrates the resulting experiment power envelope.

Table 10. Comparison of resource usage – original model and Method 5.

MODEL	ORIGINAL ENERGY (kWh)	METHOD 5 ENERGY (kWh)	COST IN ENERGY (kWh)	ORIGINAL CREW (h)	METHOD 5 CREW (h)	COST IN CREW (h)
M01	5.999	8.998	2.999	0.5	7.3	6.8
M10	4.748	7.122	2.374	0.5	6.3	5.8
M22	1.375	2.063	0.688	0.3	1.85	1.55

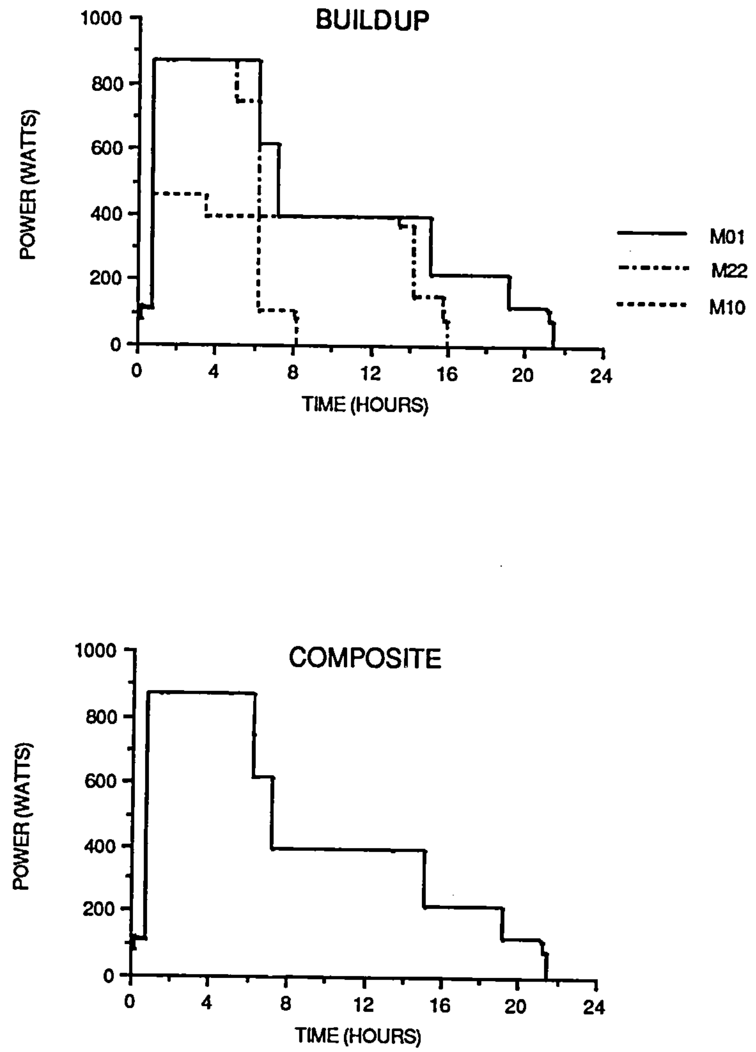


Figure 26. Experiment power envelope – Method 5.

The experiment crew profile created by combining the individual activity crew envelopes is illustrated in figure 27. A performance of M01 would utilize the first and third crew periods. A performance of M22 would utilize the first and second crew periods, and an M10 performance would utilize only the first crew period.

Experiment margins for power and crew are presented in figure 28. The margins indicate the amount of power and crew in the envelope which would not be utilized by a performance of the particular activity. This is the cost of adding flexiblity through the use of the experiment envelope. The percent power margins for individual activity envelopes within the composite profile are 50 percent for M01, 74 percent for M22, and 549 percent for M10. Additional crew time for the individual activities within the experiment envelope ranges from 9.9 h for M01 and M22 to 19.8 h for M10. The experiment envelope allows for one run of any single activity with 3.4-h flexibility for M01, 2.9 h for M22, and 1.5 h for M10.

Smoothing the beginning and end of the experiment power envelope as identified in figure 29, to facilitate ease of scheduling and add flexibility, will result in a 3.6-percent increase in the power profile. The method could be modified to allow for an additional M10 run at hour 13 at a cost of 5.3-percent increase in the experiment power envelope, but no increase in the crew envelope.

Summary

Method 5—Increase Constraining Resource by Fixed Percentage—adds flexibility to an activity by increasing the allocation of a constraining resource. In the examples presented, power was utilized as the constraining resource and 50 percent as the designated increase. This resulted in a 50-percent increase in the amount of power required to be reserved and very large increases in the amount of crew time required for the individual activity envelopes.

The experiment envelope created allows for one run of any one of the three activities. This resulted in an excess of reserved power of 50 percent to 549 percent depending upon the activity performed. Excess crew ranges from 10 to 20 h. The experiment envelope could be modified to allow an additional M10 run, thereby reducing wasted resources.

Method 5 has obvious advantages in that it targets a scarce resource. The amount of the resource available is increased by a fixed percentage which allows step durations to be increased. It can provide good flexibility in allowing late start time and longer step durations, but may in some cases prove costly in terms of added resources.

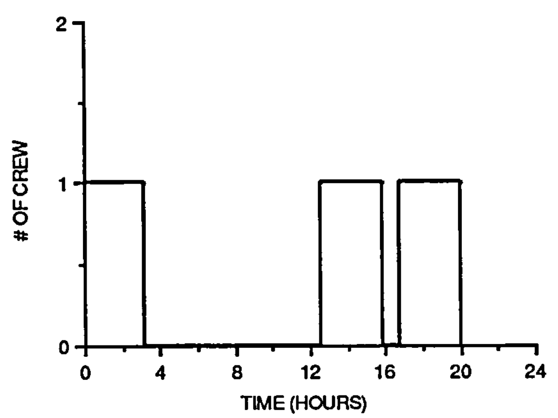
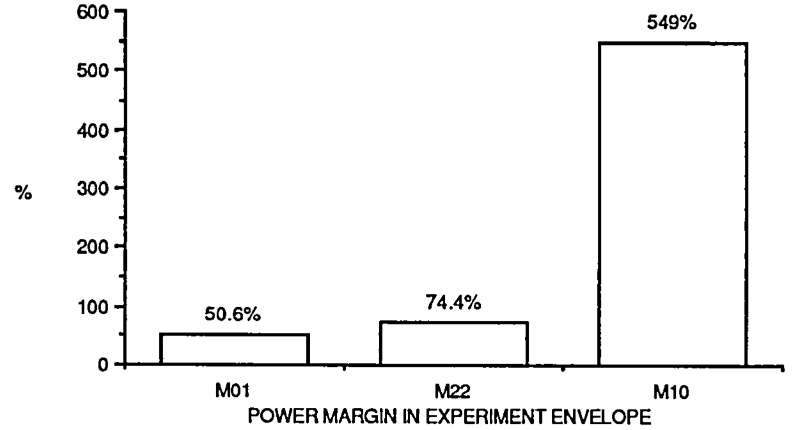


Figure 27. Experiment crew envelope – Method 5.



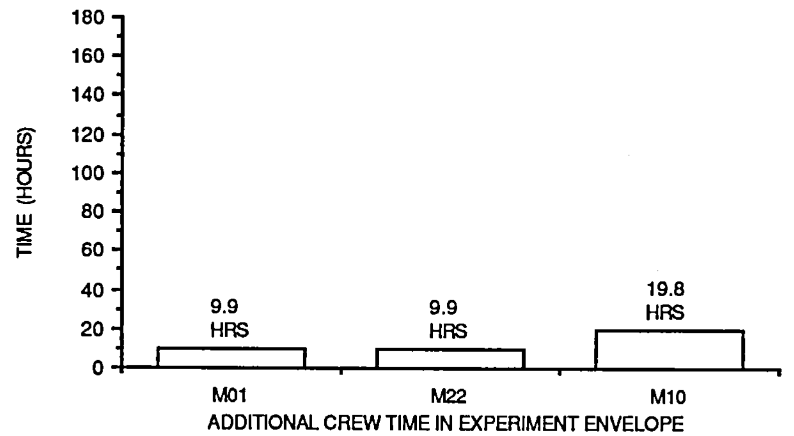


Figure 28. Experiment resource envelope analysis – Method 5.

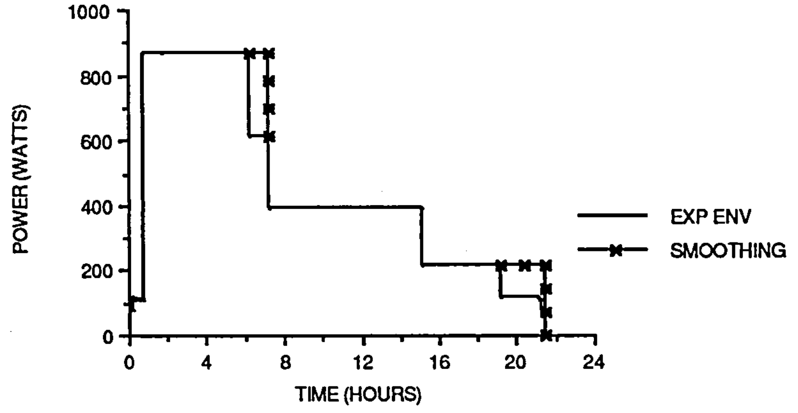


Figure 29. Smoothing experiment power envelope – Method 5.

METHOD 6 – INCREASE OPERATIONALLY VARIABLE STEPS

Method 6—Increase Operationally Variable Steps—applies either a fixed percentage of time or a fixed length of time to only those steps which are most operationally variable. Activity steps involving crew, for example, are often more operationally variable than steps which are hardware/software driven.

To illustrate this method, an arbitrary 5-min additional time has been added to each activity step involving crew in the three activity models, M01, M22, and M10. For models M01 and M22 this results in an increase of 25 min in the activity run time; 5 min for each of the first three steps and 5 min for the last two steps. M10 has an increase of 15 min in the activity run time; 5 min for each of the first three steps.

The power profiles for Method 6 are illustrated in figure 30. Figure 31 illustrates the crew profiles. The additional 25-min run time for activities M01 and M22, and the additional 15-min run time for M10 can be noted from the power and crew profiles.

The increase in energy and crew due to the added flexibility is presented in figure 32. The percent power margin is 4 percent for M01, 5 percent for M22, and nearly 10 percent for M10. Additional crew time required ranges from 15 min for M10 to 25 min for M01 and M22. The margins represent the cost of the activity envelopes.

A comparison of the power and crew usage for the original activity requirement and Method 6 is provided in table 11. The second and third columns list the energy required by the original activity and Method 6, respectively. The fourth column lists the cost in energy as 0.244 for M01, 0.251 for M22, and 0.133 for M10.

The fifth and sixth columns of table 11 list the crew time required by the original activity and Method 6, respectively. The seventh column lists the increase in crew time as 25 min for both M01 and M22 and 15 min for M10.

An experiment envelope was created for activities M01, M22, and M10 by overlapping the individual activity profiles. The experiment envelope allows for one run of any one of the three activities. The overlapping of the individual power profiles is shown in the top profile of figure 33. The lower profile of figure 33 shows the resulting experiment envelope for power. Figure 34 illustrates the experiment profile for crew created by overlapping the three individual activity crew profiles.

The margins of increase in power and crew, required to be scheduled for the experiment envelope over that in the individual activity envelopes, are depicted in figure 35. The power increases are less than 1 percent for M01, 25 percent for M22, and 315 percent for M10. Additional crew time ranges from 52 min for M01 and M22 to 74 min for M10. These marginal increases represent the cost of adding flexibility through an experiment envelope.

The experiment power envelope was smoothed to facilitate ease of scheduling and to add flexibility. The smoothing, as depicted in figure 36, increases the energy requirement by 5.6 percent.

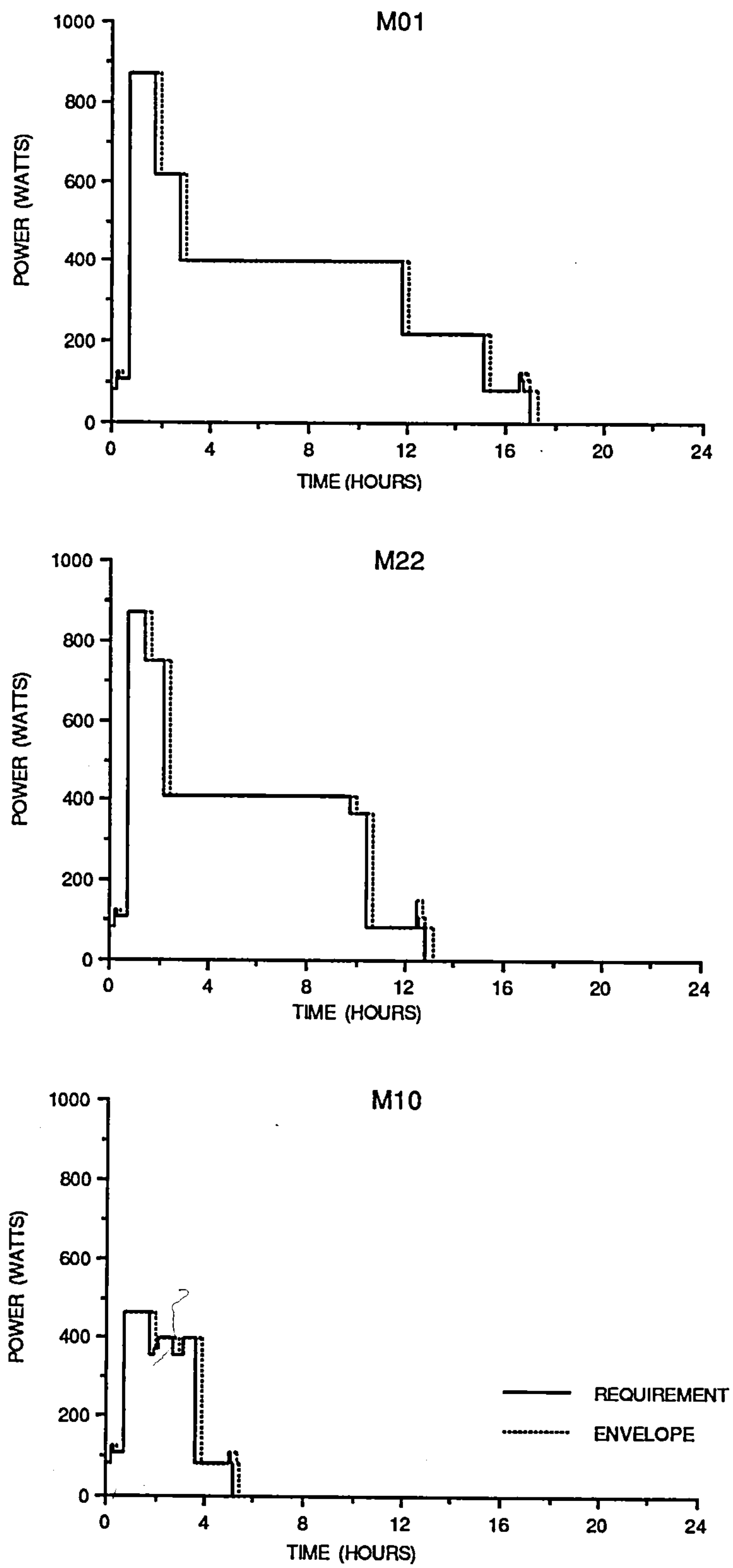


Figure 30. Individual activity power envelopes – Method 6.

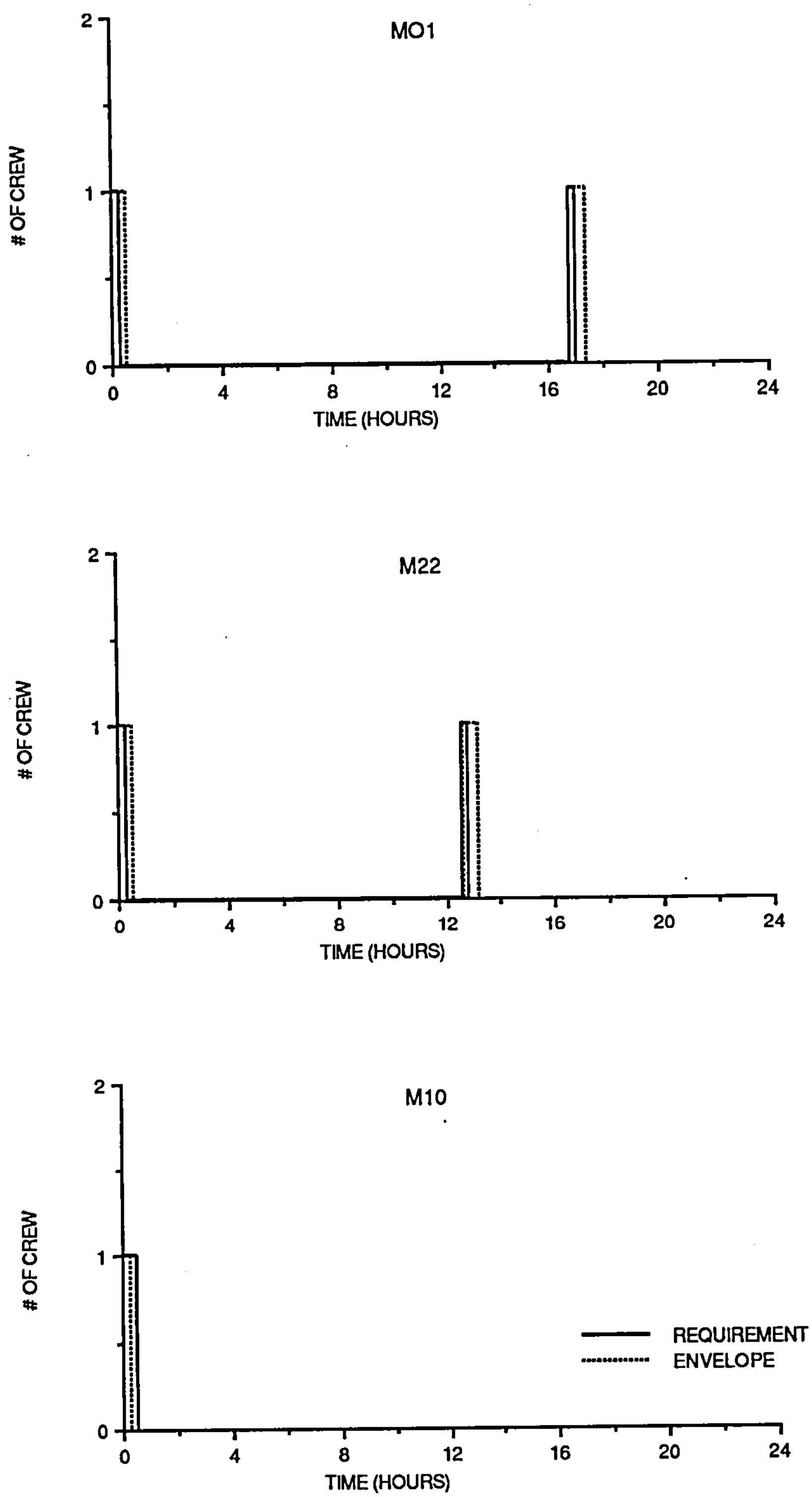
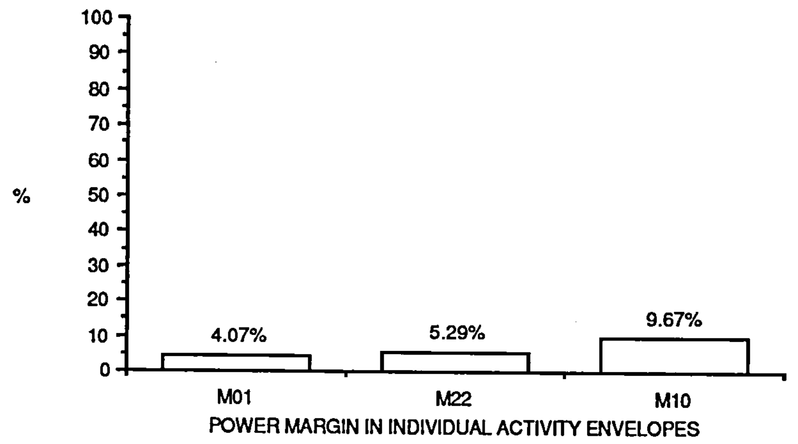


Figure 31. Individual activity crew envelopes – Method 6.



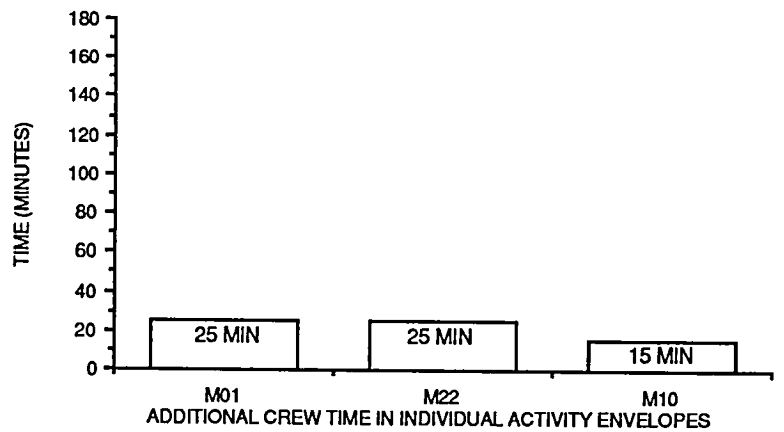
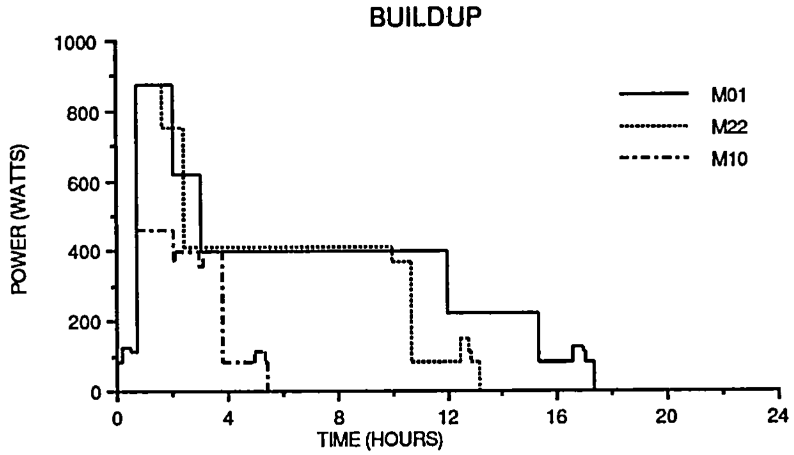


Figure 32. Power and crew resource envelope analysis – Method 6.

Table 11. Comparison of resource usage – original model and Method 6.

MODEL	ORIGINAL ENERGY (kWh)	METHOD 6 ENERGY (kWh)	COST IN ENERGY (kWh)	ORIGINAL CREW (min)	METHOD 6 CREW (min)	COST IN CREW (min)
M01	5.999	6.243	0.244	30	55	25
M22	4.748	4.999	0.251	30	55	25
M10	1.375	1.508	0.133	18	33	15



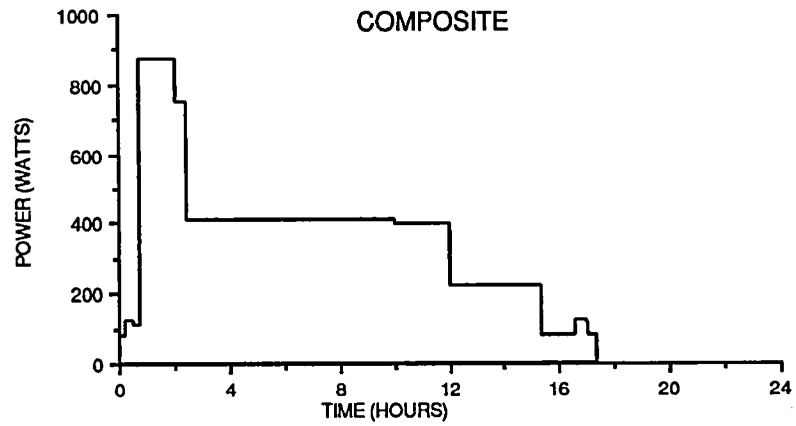


Figure 33. Experiment power envelope – Method 6.

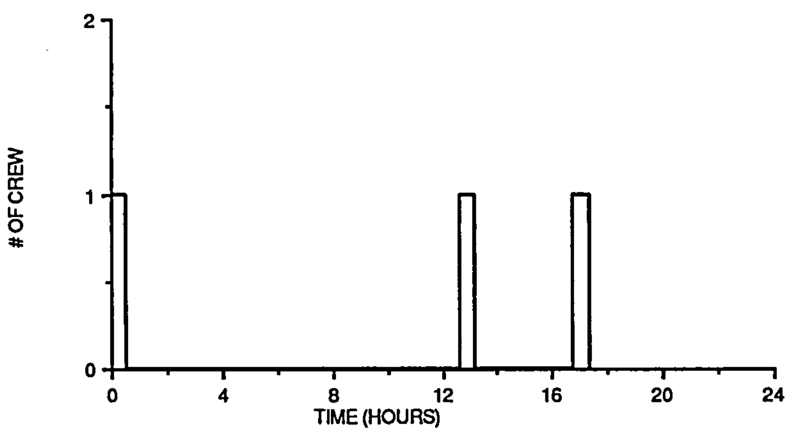
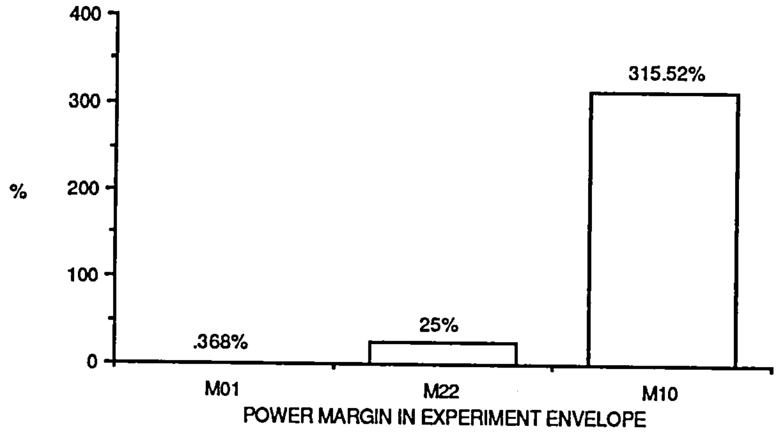


Figure 34. Experiment crew envelope – Method 6.



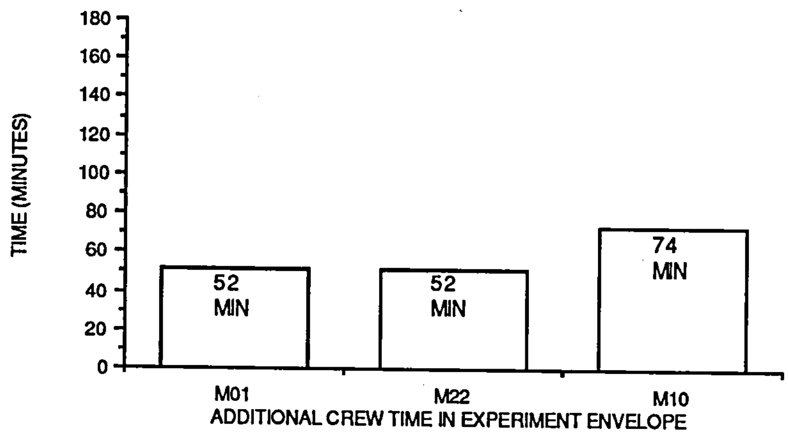


Figure 35. Experiment resource envelope analysis – Method 6.

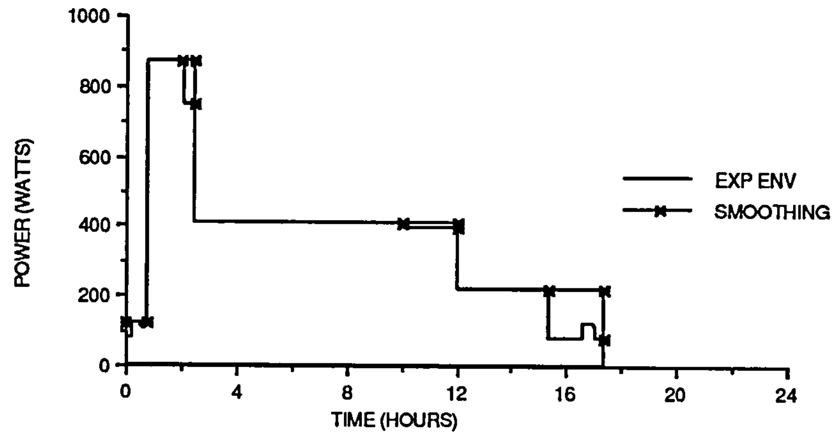


Figure 36. Smoothing experiment power envelope – Method 6.

Summary

Method 6—Increase Operationally Variable Steps—applies increased run time to only the most operationally variable steps in a model. In the examples presented, 5-min additional run time was added to each step requiring crew. This resulted in an additional 15- to 25-min run time for the activities, minor increases in power, and 15- to 25-min increased crew time.

The experiment envelope created allows for one performance of any one of the three activities, including the flexibility factor. The excess power in the experiment envelope ranges from less than 1 percent to 316 percent. The excess in crew time ranges from 52 to 74 min.

This method could be used to allow added flexibility on the first performance of an activity when the crew might not be familiar with the required procedures. The amount of flexibility could then be decreased on subsequent performances.

Method 6 allows flexibility to be added to an activity while conserving resources. The method is applicable only to those activities with a mix of operationally variable and operationally fixed steps.

METHOD 7 – VARIABLE PERCENTAGE STEP INCREASE

Method 7—Variable Percentage Step Increase—applies a variable percentage of time to each activity step based on the importance of multiple operational factors. Steps within an activity are graded relative to several factors to determine the amount of flexibility for the particular step. All resources required for the step must be made available for the increased run time.

Three cases are presented for this concept in order to illustrate various methods of implementation. The cases consider the effects of two, three, and four factors. The factors presented are for illustration only and the method can be easily modified to accommodate additional or alternative factors.

The first of the four factors considered is operational variability. Operational variability refers to the likelihood of an individual step requiring more run time than normally allotted. For example, a step requiring crew would have a high variability, whereas a step which is software driven would have low variability.

Percent of activity complete is the second factor considered. The percent of activity complete is calculated based on the run time of the steps completed prior to the beginning of the current step. A higher degree of flexibility is allotted to steps toward the end of the activity. Since valuable resources are being expended throughout the actvity, a failure toward the end of the activity would result in a higher rate of wasted resources than a failure near the beginning. It would, therefore, be desirable to ensure resources are available to complete an activity which is nearing its end.

Science priority is the third factor. Science priority in this example is the priority of the activity in relation to other activities. Thus, every step in the activity will have the same science priority assigned. In models where all activity steps are not vital to completion of the activity, the priority could be based on steps within the activity.

The final factor considered is percent of activity resources. Percent of activity resources is calculated based on the most limiting resource for the mission increment. For each step in an activity, the amount of the limiting resource required for the step is divided by the amount of the resource required for the entire activity to determine the percent of activity resources. Steps requiring the highest percentages of the limiting resource are likely to be most critical to the completion of the activity.

The method as presented herein requires a delay when an activity step completes before the full step duration. The method can also be implemented to allow follow-on steps to begin immediately. This entails reserving resources for both the current step and the successive step during the step margin. The amount of resources which must be reserved for each performance of a model is therefore higher if follow-on steps are permitted to begin immediately after completion of the predecessor step.

Case 1

Case 1 considers the combined effect of two factors: operational variability and percent of activity complete. For each step in the activity, a weight is assigned for the operational variablity of the step. For this illustration, variability has been arbitrarily rated on a scale from 1 to 10, with 1 indicating low variablity and 10 indicating high variability. The percent of the activity complete has been calculated based on the duration of the activity prior to the current step.

After the operational variability and percent of activity complete have been determined, the percentage for the step increase can be read from a table. For this illustration, arbitrary percentages have been assigned and are indicated in table 12. The rows represent the level of operational variability and the columns represent the percent of the activity complete. A step with medium variability and 30 percent of the activity complete would receive an envelope of 15 percent (row 2, column 2). That is, the step duration would be increased by 15 percent of its original run time.

To illustrate the application of case 1 on activity M01, arbitrary weights have been assigned for the operational variabilty. These assumptions are listed in the second column of table 13. The third column of table 13 lists the calculated percent of the activity complete prior to the current step. The fourth column lists the increase for each step as read from table 12. For illustrative purposes, the same operational variabilty has been assigned to M22 and M10.

Table 12. Resource envelope percentages – case 1.

		Percent of Activity Complete			
		< 25%	25 - 50%	50 - 75%	> 75%
Operational Variability	Low (1-3)	5%	10%	15%	20%
	Med (4-7)	10%	15%	20%	25%
	High (8-10)	20%	25%	30%	35%

Table 13. Step variabilty – Method 7, case 1.

Step	Operational Variability	% Activity Complete	Resource Envelope %
1	1	0.0	5
2	1	0.5	5
3	2	1.5	5
4	4	1.8	10
5	4	3.2	10
6	5	4.7	10
7	5	10.6	10
8	8	16.5	20
9	7	69.5	20
10	5	89.0	25
11	2	97.9	20
12	4	98.5	25
13	2	98.6	20
14	1	98.8	20
15	1	99.9	20

The activity power profiles resulting from the application of case 1 are presented in figure 37. The resulting activity crew envelopes are presented in figure 38. As can be seen in figure 38, there is a shift in the time crew is required for the terminating steps of activities M01 and M22, as well as an increase in the amount of time required.

The increase in energy consumption and crew usage due to the added flexibility is indicated in figure 39. The percent increase in the amount of power required is 17 to 18 percent for all three models. Crew is increased less than 1 min for M10 and 3 min for M01 and M22. These increases represent the cost of the activity envelopes.

A comparison of the energy and crew requirements for the original activity and Method 7, case 1, is provided in table 14. The cost in energy is reflected in the fourth column. There is an increase of 1.048 kWh for activity M01, 0.85 kWh for M22, and 0.234 kWh for M10. The cost in crew time is reflected in the seventh column. Crew is increased 3.3 min for activities M01 and M22 and less than 1 min for M10.

An experiment envelope was created allowing one run of any one of the three activities. The buildup and composite profiles for power for activities M01, M22, and M10 are illustrated in figure 40. The experiment profile for crew resulting from the composite envelope is depicted in figure 41.

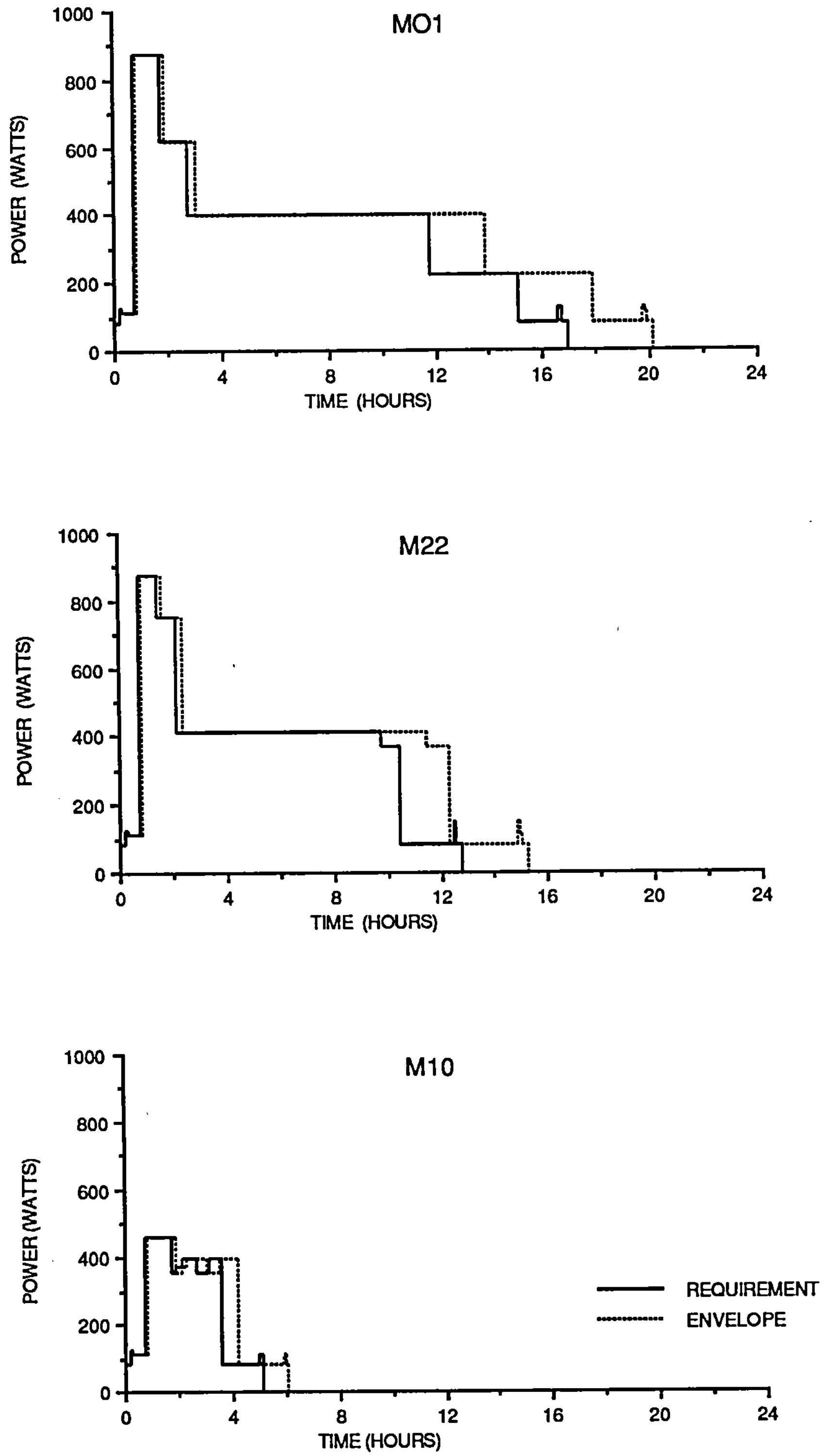


Figure 37. Individual activity power envelopes – Method 7, case 1.

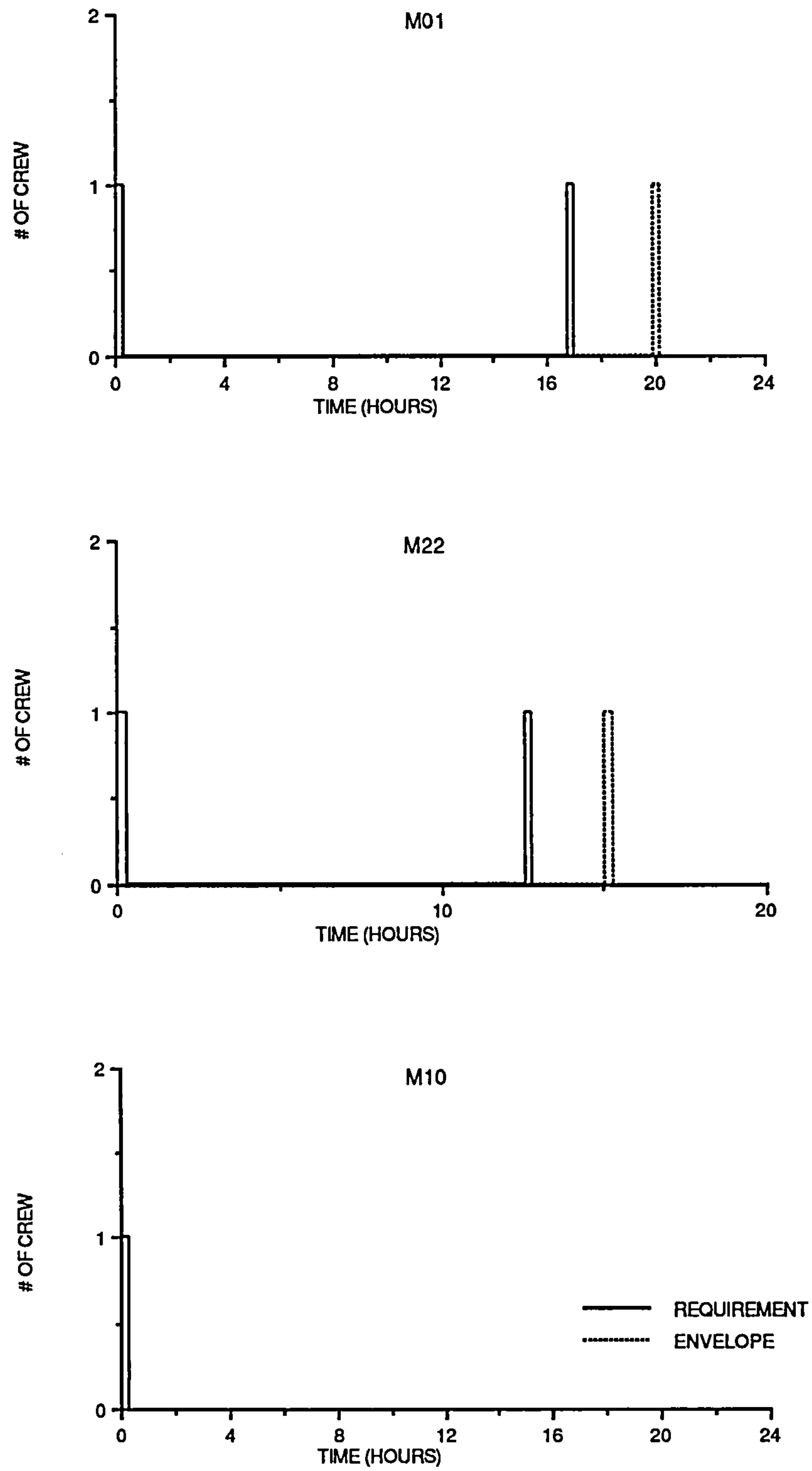
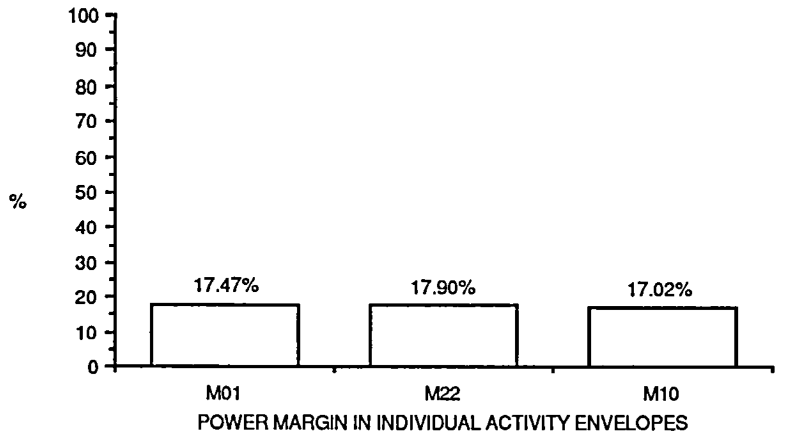


Figure 38. Individual activity crew envelopes – Method 7, case 1.



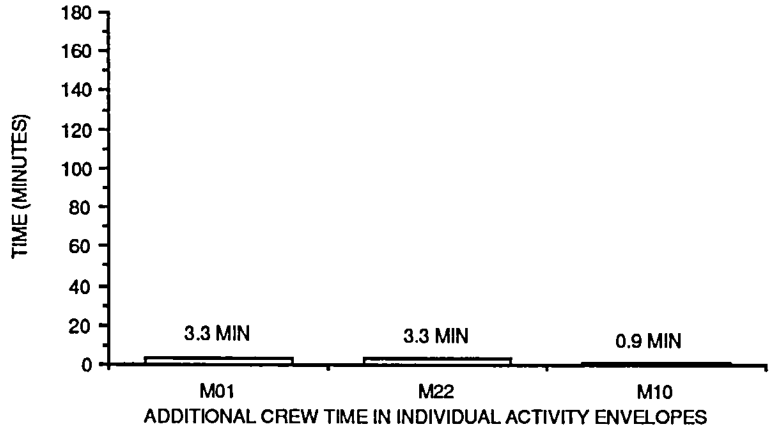


Figure 39. Power and crew resource envelope analysis – Method 7, case 1.

Table 14. Comparison of resource usage – original model and Method 7, case 1.

MODEL	ORIGINAL ENERGY (kWh)	METHOD 7 CASE 1 ENERGY (kWh)	COST IN ENERGY (kWh)	ORIGINAL CREW (min)	METHOD 7 CASE 1 CREW (min)	COST IN CREW (min)
M01	5.999	7.047	1.048	30	33.3	3.3
M22	4.748	5.598	0.850	30	33.3	3.3
M10	1.375	1.609	0.234	18	18.9	0.9

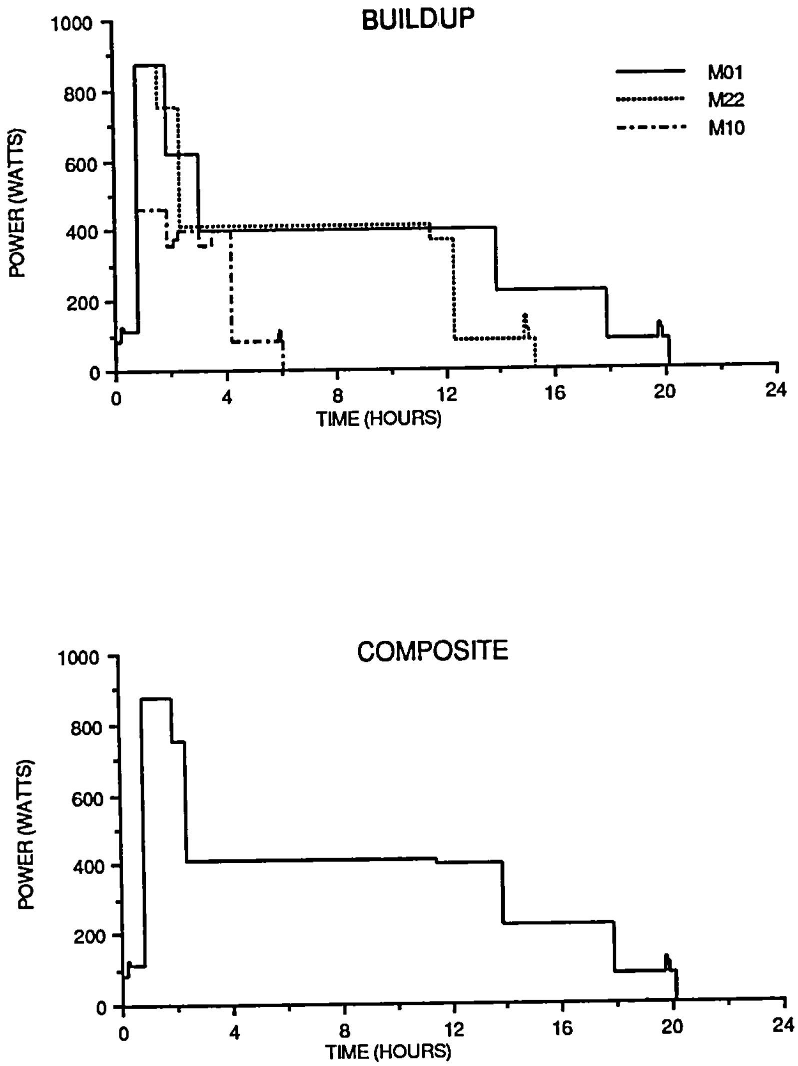


Figure 40. Experiment power envelope – Method 7, case 1.

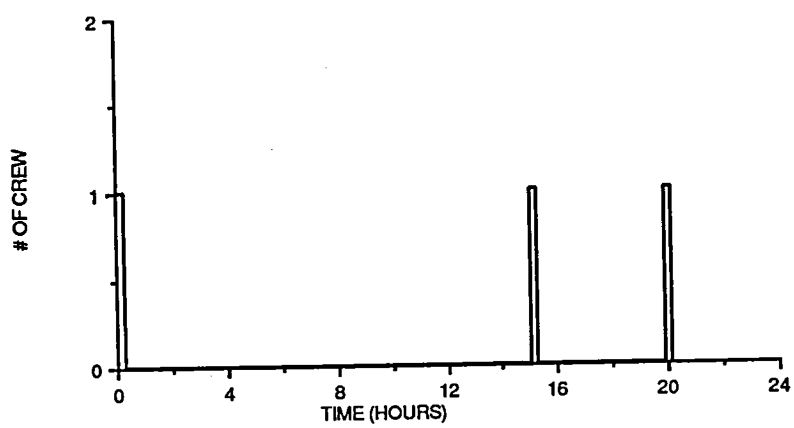


Figure 41. Experiment crew envelope – Method 7, case 1.

The energy and crew margins for the individual activities within the experiment envelope are indicated in figure 42. The amount of power required to be scheduled is increased less than 1 percent for M01, 26 percent for M22, and 340 percent for M10. The amount of crew time required to be scheduled is increased 14 min for M01 and M22 and nearly 29 min for M10. These margins represent the cost of the experiment envelope.

Smoothing the experiment profile for power is depicted in figure 43. The additional flexibility results in an increase of 5.7 percent in the amount of power required to be reserved for the experiment.

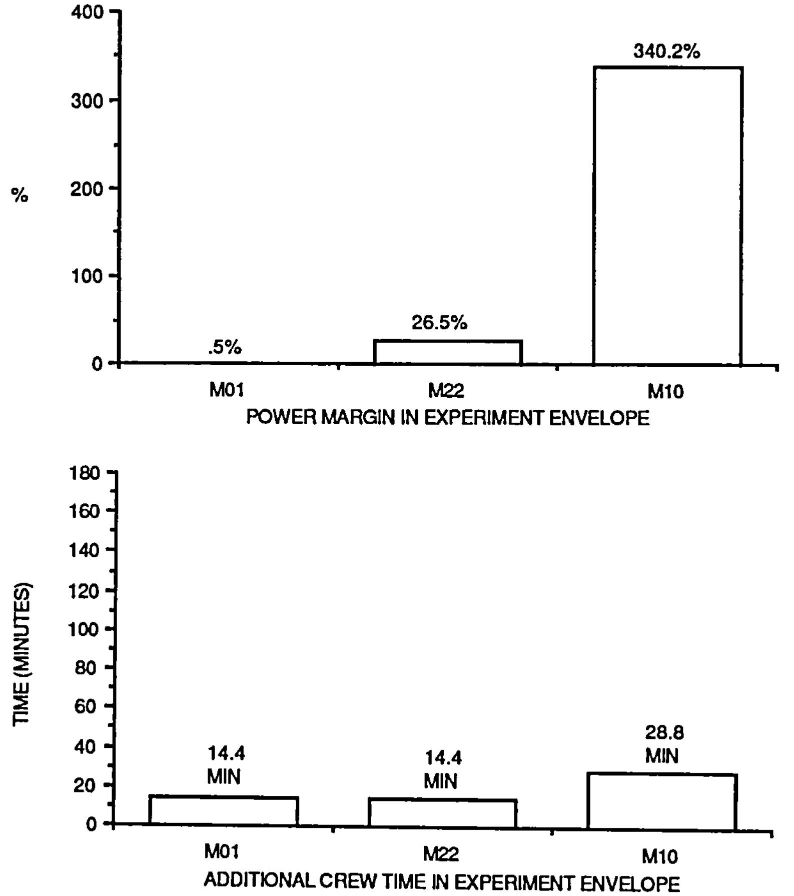


Figure 42. Experiment resource envelope analysis – Method 7, case 1.

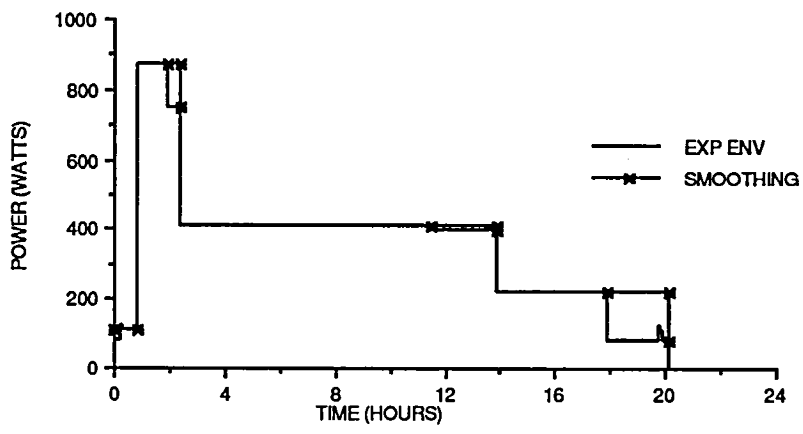


Figure 43. Smoothing experiment power envelope – Method 7, case 1.

Case 2

Resource envelope Method 7, case 2, considers the combined effect of three factors: operational variability, percent of activity complete, and science priority. Operational variability and percent of activity complete are determined as in case 1. The science priority of the activity relative to other activities must be determined through some judgmental method.

After the operational variability, percent of activity complete, and science priority have been determined for each step, the step increase can be read from a three-dimensional array. The cube in figure 44 illustrates the progression of the envelope percentages. A low percentage would be assigned to activity steps with low operational variability, low science priority, and a small percent of activity complete. A high percentage of increase would be assigned to activity steps with high operational variability, high science priority, and a large percent of activity complete. The numbers in the cube represent the increase in step envelope percentages, not the actual percentages. For example, a step with low operational variability, low science priority, and 80 percent of activity complete would receive a level 4 increase (row 1, column 4, depth 1). That is, the step duration would be increased by a level 4 percentage of the original run time.

Case 2 can be implemented by assigning percentages to the 9 levels in the cube in order to determine step envelope percentages. To illustrate case 2, the science priority of the three models has been given an arbitrary rating of 5. The table values have been multiplied by 5 to determine percent increases, resulting in envelopes of 5 to 45 percent. Table 15 presents the procedure for calculating the step envelopes for M01. The third, fourth, and fifth columns of table 15 list the step values for the three factors considered. The percent of increase as determined from figure 44 is listed in the sixth column. The seventh and eighth columns list step increase and total duration of each step. The step variability for models M22 and M10 has been calculated in the same manner.

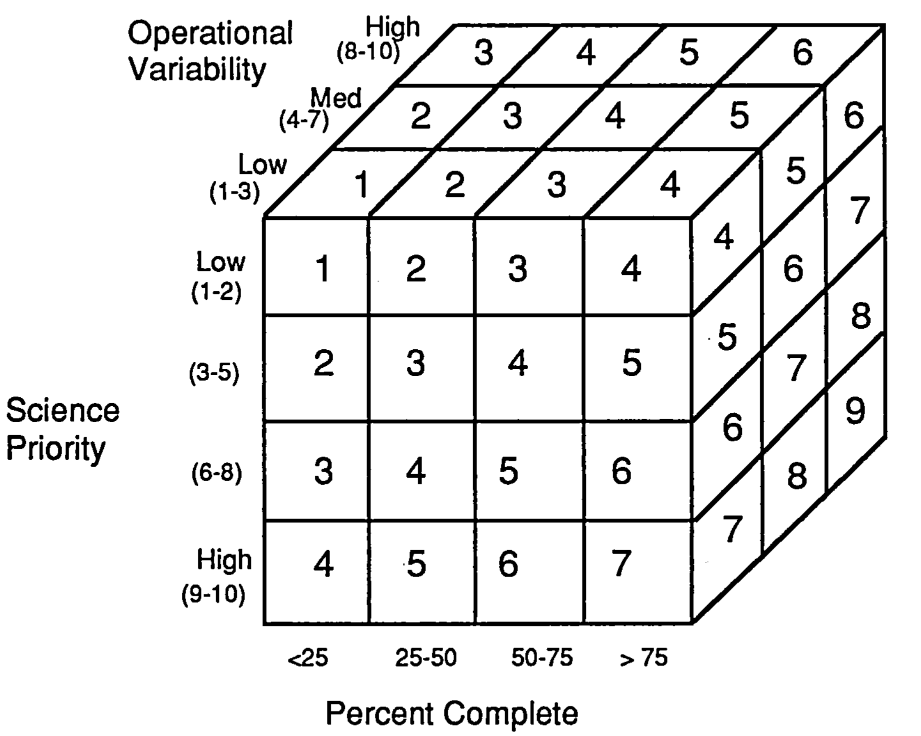


Figure 44. Resource envelope percentages, Method 7, case 2.

Table 15. Step variabilty – Method 7, case 2.

STEP	DURATION	SCIENCE PRIORITY	OPERATIONAL VARIABILITY	PERCENT ACTIVITY COMPLETE	STEP 5 INCREASE	ENVELOPE DURATION	TOTAL STEP DURATION
1	5	5	1	0	10	0.50	5.50
2	10	5	1	0.5	10	1.00	11.00
3	3	5	2	1.5	10	0.30	3.30
4	15	5	4	1.8	15	2.25	17.25
5	15	5	4	3.2	15	2.25	17.25
6	60	5	5	4.7	15	9.00	69.00
7	60	5	5	10.6	15	9.00	69.00
8	540	5	8	16.5	20	108.00	648.00
9	200	5	7	69.5	25	50.00	250.00
10	89	5	5	89.1	30	26.70	115.70
11	6	5	2	97.9	25	1.50	7.50
12	1	5	4	98.4	30	0.30	1.30
13	3	5	2	98.5	25	0.75	3.75
14	10	5	1	98.8	25	2.50	12.50
15	2	5	1	99.8	25	0.50	2.50

The power and crew profiles for case 2 are depicted in figures 45 and 46, respectively. As in case 1, there is a delay in the time crew is required for the terminating steps of activities M01 and M22.

The cost of the activity envelopes is the increase in resources. The increase in energy consumption and crew usage due to the added flexibility is presented in figure 47. The amount of power required increases approximately 19 percent for each of the three models. Crew required increases 1.8 min for M10 and 4.8 min for M01 and M22.

A comparison of the original resource usage with that of Method 7, case 2, is provided in table 16. The fourth column shows the increase in power to be 1.17 kWh for activity M01, 0.932 kWh for M22, and 0.265 kWh for M10. The cost in crew is listed in the seventh column. The cost is 4.8 min for activities M01 and M22 and 1.8 min for M10.

An experiment envelope for power and crew can be created by overlapping the respective power and crew profiles for the three individual activity models. Figure 48 illustrates the overlapping of the

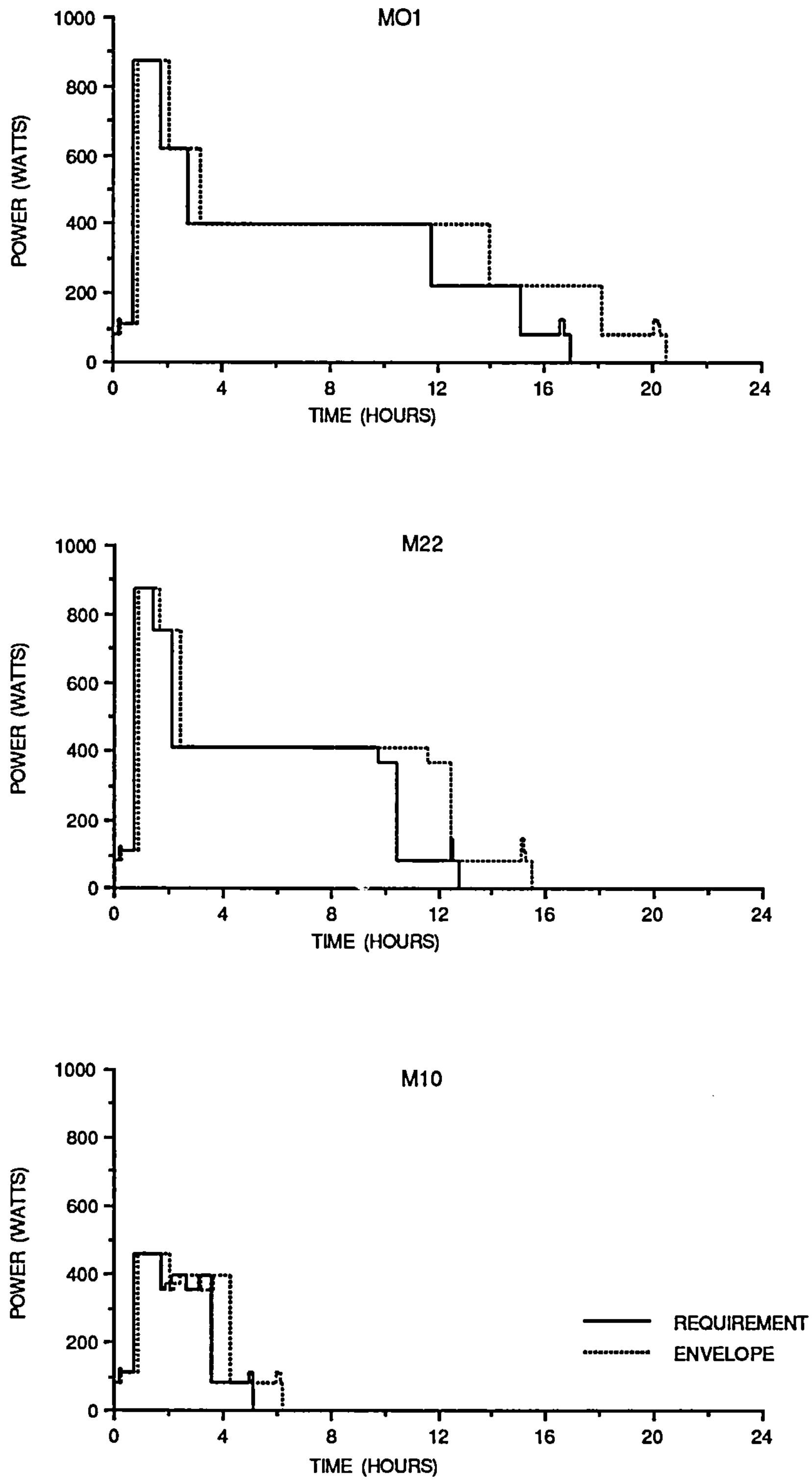


Figure 45. Individual activity power envelopes – Method 7, case 2.

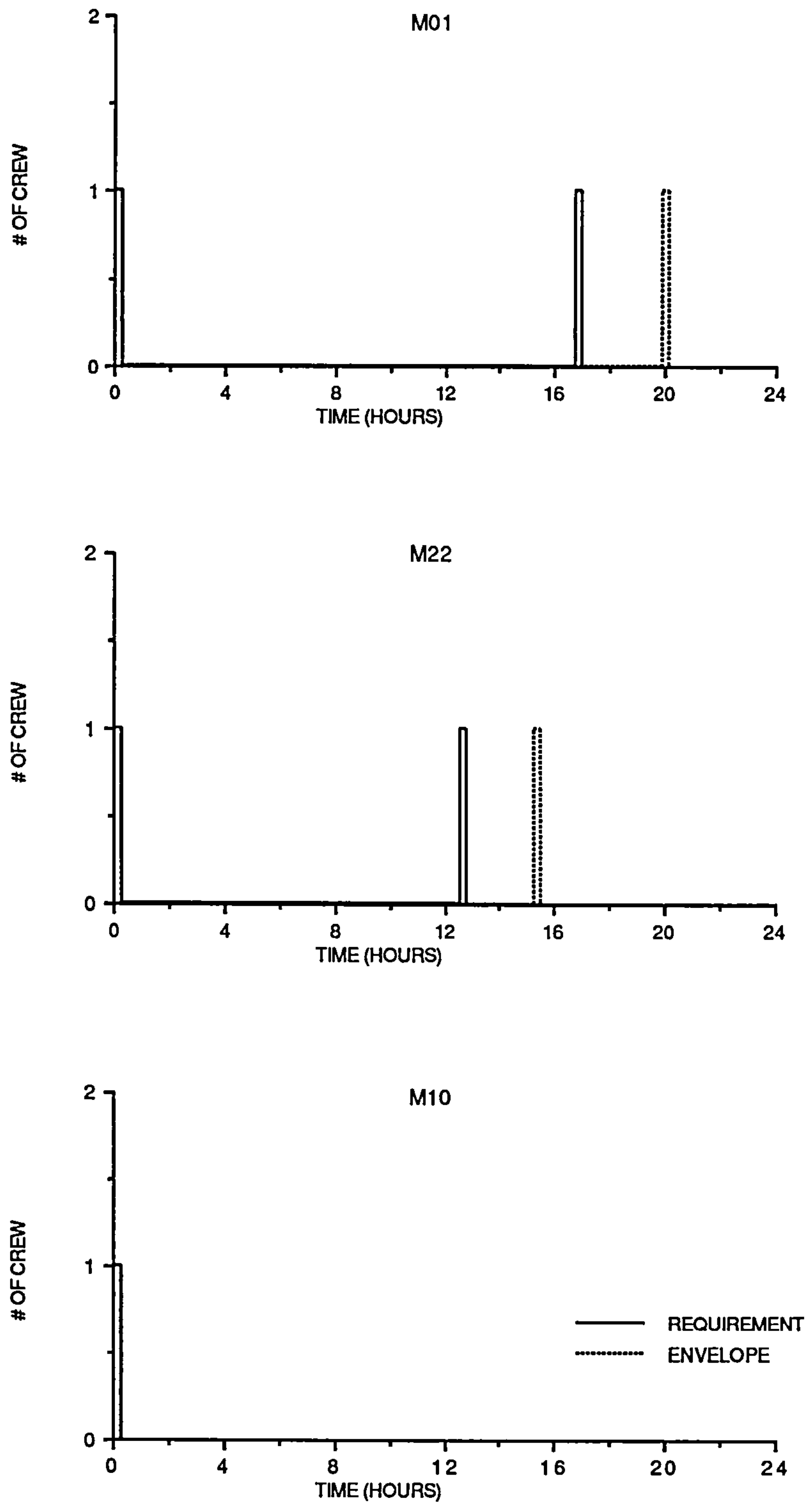
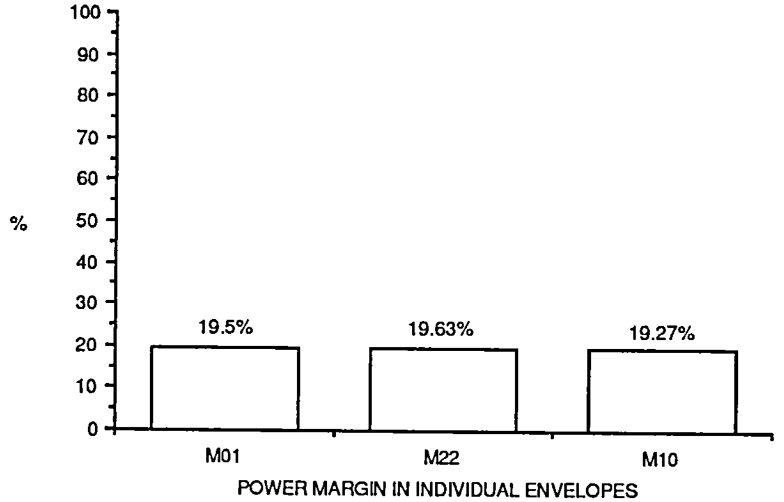


Figure 46. Individual activity crew envelopes – Method 7, case 2.



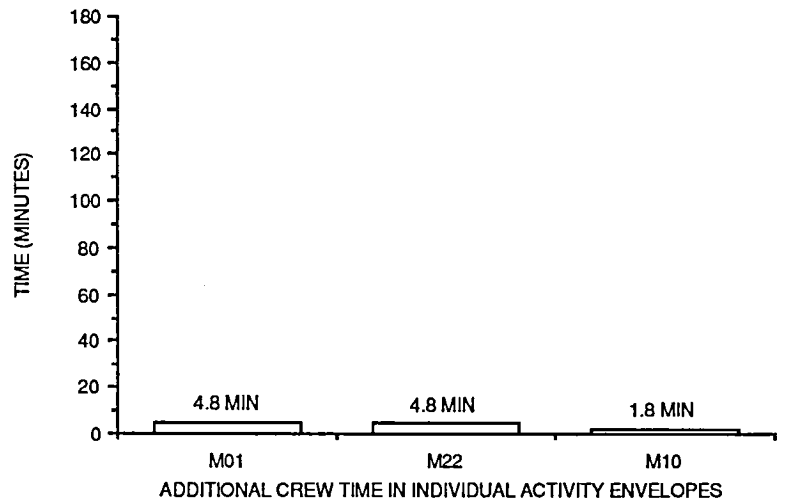
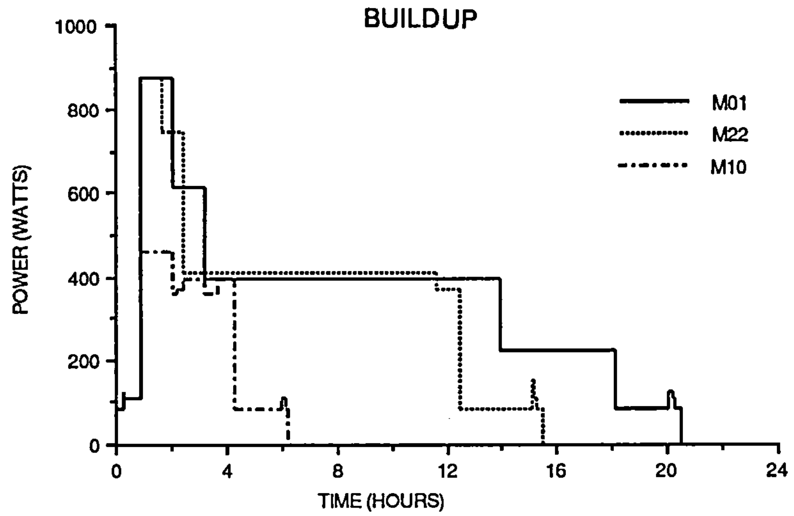


Figure 47. Power and crew resource envelope analysis – Method 7, case 2.

Table 16. Comparison of resource usage – original model and Method 7, case 2.

MODEL	ORIGINAL ENERGY (Watts)	METHOD 7 CASE 2 ENERGY (Watts)	COST IN ENERGY (kWh)	ORIGINAL CREW (min)	METHOD 7 CASE 2 CREW (min)	COST IN CREW (min)
M01	5.999	7.169	1.170	30	34.8	4.8
M22	4.748	5.680	0.932	30	34.8	4.8
M10	1.375	1.640	0.265	18	19.8	1.8



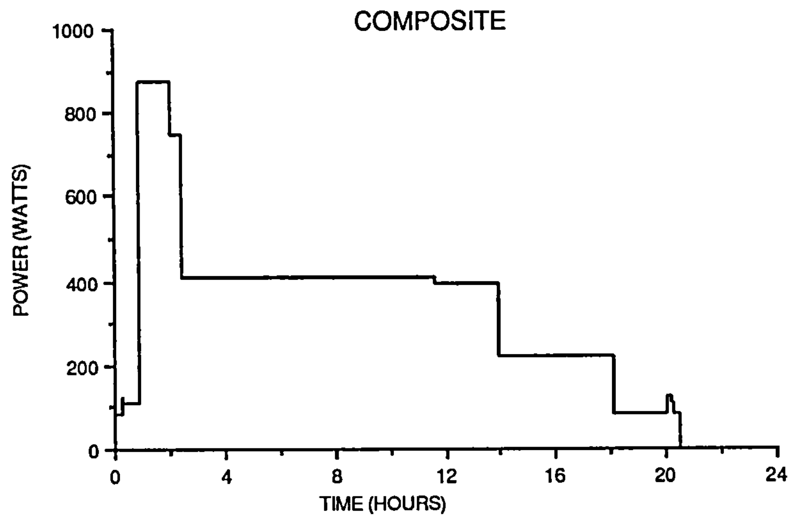


Figure 48. Experiment power envelope – Method 7, case 2.

individual activity power envelopes and the resulting experiment envelope. The experiment envelope for crew resulting from the overlapping of the individual activity crew envelopes is illustrated in figure 49. The experiment envelope allows for one run of any one of the three activities.

The margins of increase for each of the individual activity envelopes within the experiment envelope are presented in figure 50. The amount of power required to be scheduled increases less than 1 percent for M01, 27 percent for M22, and 339 percent for M10. The amount of crew required to be scheduled increases 15 min for M01 and M22 and 30 min for M10. These increases represent the cost of the experiment envelope.

Smoothing of the composite power profile to facilitate ease of scheduling is depicted in figure 51. This results in an increase of 6 percent in the amount of power required to be scheduled for the experiment.

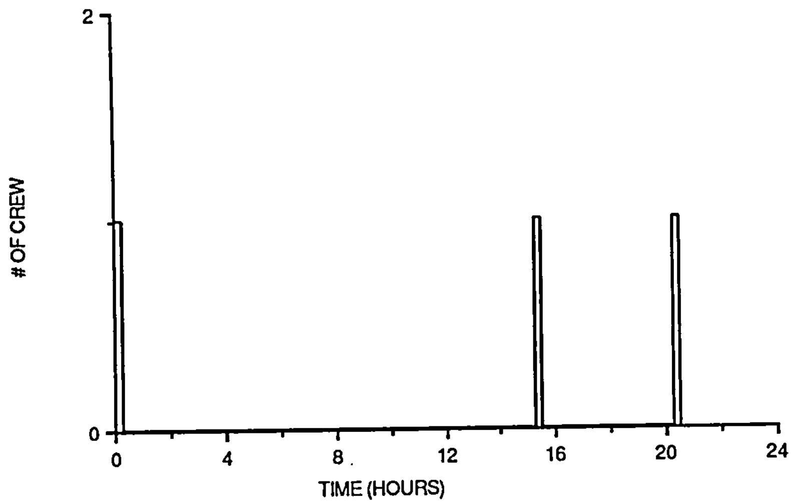
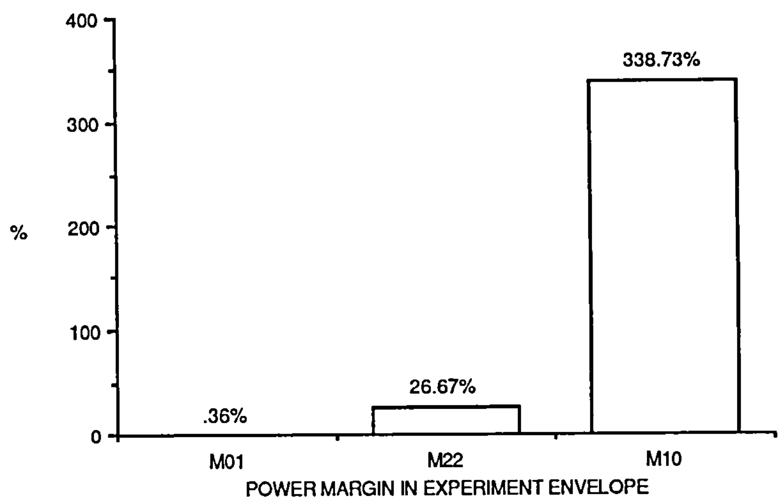


Figure 49. Experiment crew envelope – Method 7, case 2.



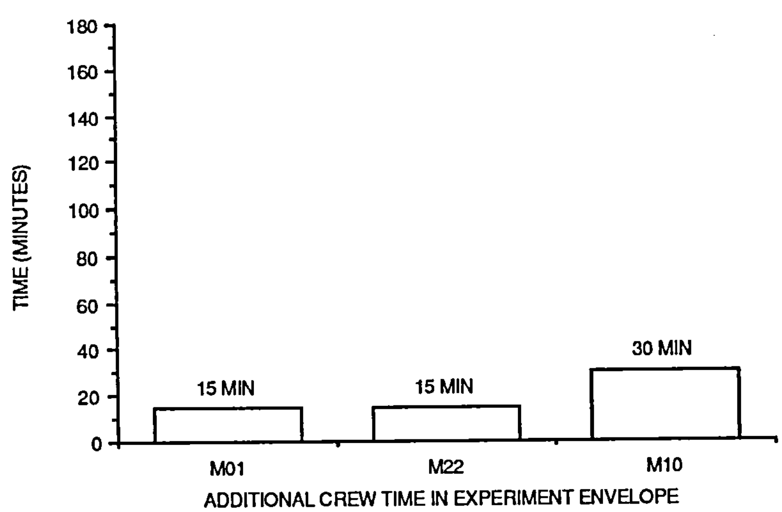


Figure 50. Experiment resource envelope analysis – Method 7, case 2.

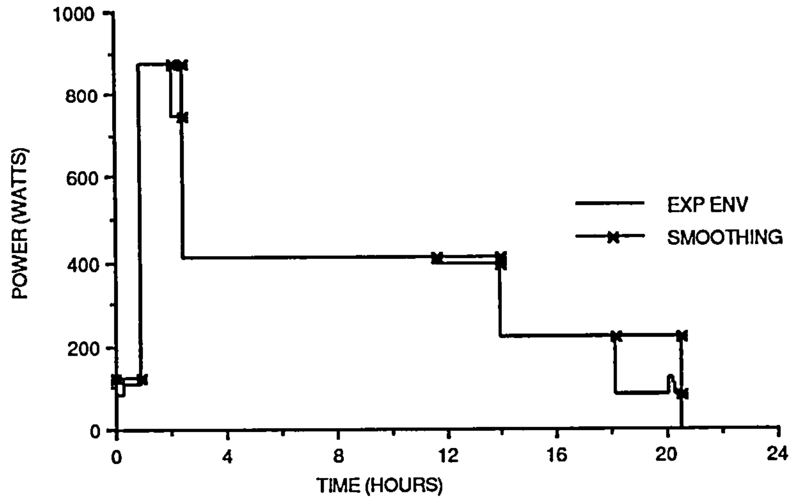


Figure 51. Smoothing experiment power envelope – Method 7, case 2.

Case 3

Resource envelope Method 7, case 3, considers the combined effect of four factors: operational variability, percent of activity complete, science priority, and percent of activity resources. The first three factors are determined as in cases 1 and 2. Percent of activity resources is calculated by dividing the amount of the resource required for the step by the amount required for the entire activity.

Case 3 uses the following equation and procedure for determining the step envelope percentages.

Equation:

$$\text{Envelope percent} = \text{Science Priority} + \text{Operational Variability} + \text{Percent Complete} + \text{Percent of Activity Resources}$$

Procedure:

1. Determine maximum percent increase for any one activity step.

2. Divide maximum percent by number of factors.

3. For each step, grade each factor on a scale from 0 to the result of step 2.

4. Total of factor grades is step envelope percentage.

To illustrate this case for M01, energy is assumed as the limiting factor. An arbitrary 40-percent maximum step increase has been designated for this activity. Since four factors are being considered, each factor is allotted 10 percent, and all values are scaled from 0 (low) to 10 (high). Table 17 lists the factor grades for each step and the resulting step envelopes.

Table 17. Step variabilty – Method 7, case 3.

STEP	DURATION (MINUTES)	SCIENCE PRIORITY	OPERATIONAL VARIABILITY	PERCENT ACTIVITY COMPLETE	PERCENT ACTIVITY RESOURCES	STEP INCREASE	ENVELOPE DURATION	TOTAL STEP DURATION
1	5	5	1	0.00	0.01	6.01	0.30	5.30
2	10	5	1	0.05	0.02	6.07	0.61	10.61
3	3	5	2	0.15	0.01	7.16	0.21	3.21
4	15	5	4	0.18	0.05	9.23	1.38	16.38
5	15	5	4	0.32	0.05	9.37	1.40	16.40
6	60	5	5	0.47	1.45	11.92	7.15	67.15
7	60	5	5	1.06	1.02	12.08	7.25	67.25
8	540	5	8	1.65	5.93	20.58	111.11	651.11
9	200	5	7	6.95	1.21	20.16	40.32	240.32
10	89	5	5	8.90	0.20	19.10	17.00	106.00
11	6	5	2	9.79	0.02	16.81	1.01	7.01
12	1	5	4	9.84	0.00	18.84	0.19	1.19
13	3	5	2	9.85	0.01	16.86	0.51	3.51
14	10	5	1	9.88	0.02	15.90	1.59	11.59
15	2	5	1	9.98	0.01	15.99	0.32	2.32

Science priority has been given an arbitrary rating of 5 as is indicated in the third column of table 17. The operational variability assumed in case 1 is again assumed for this case and is listed in the fourth column. The percent of activity complete was also calculated as in case 1. The percent activity complete for each step was divided by 10 to change the 0-to-100 scale to a 0-to-10 scale. The results are listed in the fifth column. The percent of activity resources was calculated by dividing the amount of energy used for each step by the total amount of energy used in the activity. The percents were again divided by 10 to reduce the scale to 0 to 10. The percent of activity resources is listed in the sixth column.

To determine the step increase, the scaled values for factors 1 through 4 (third through sixth columns of table 17) were added across each row. The sum, seventh column, is the percentage of increase in run time for the step. The eighth column indicates the number of minutes the step is increased and the ninth column gives the total step duration for case 3. Activity models M22 and M10 have been assigned the same variability for illustration.

The activity power envelopes resulting from the application of case 3 are presented in figure 52. The resulting activity crew envelopes are presented in figure 53. As in cases 1 and 2, there is a shift in the time crew is required for the terminating steps, due to the cumulative nature of the step envelopes.

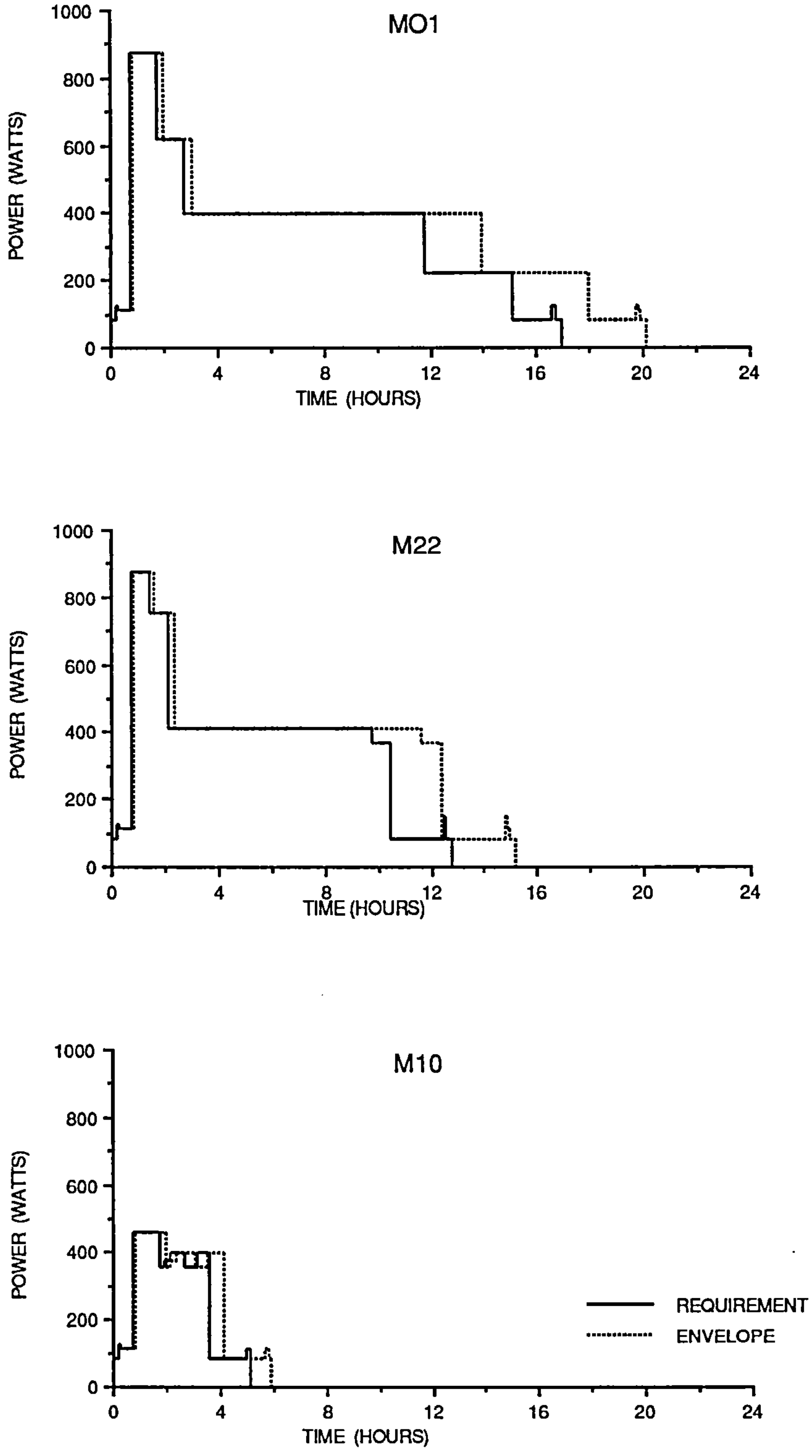


Figure 52. Individual activity power envelopes – Method 7, case 3.

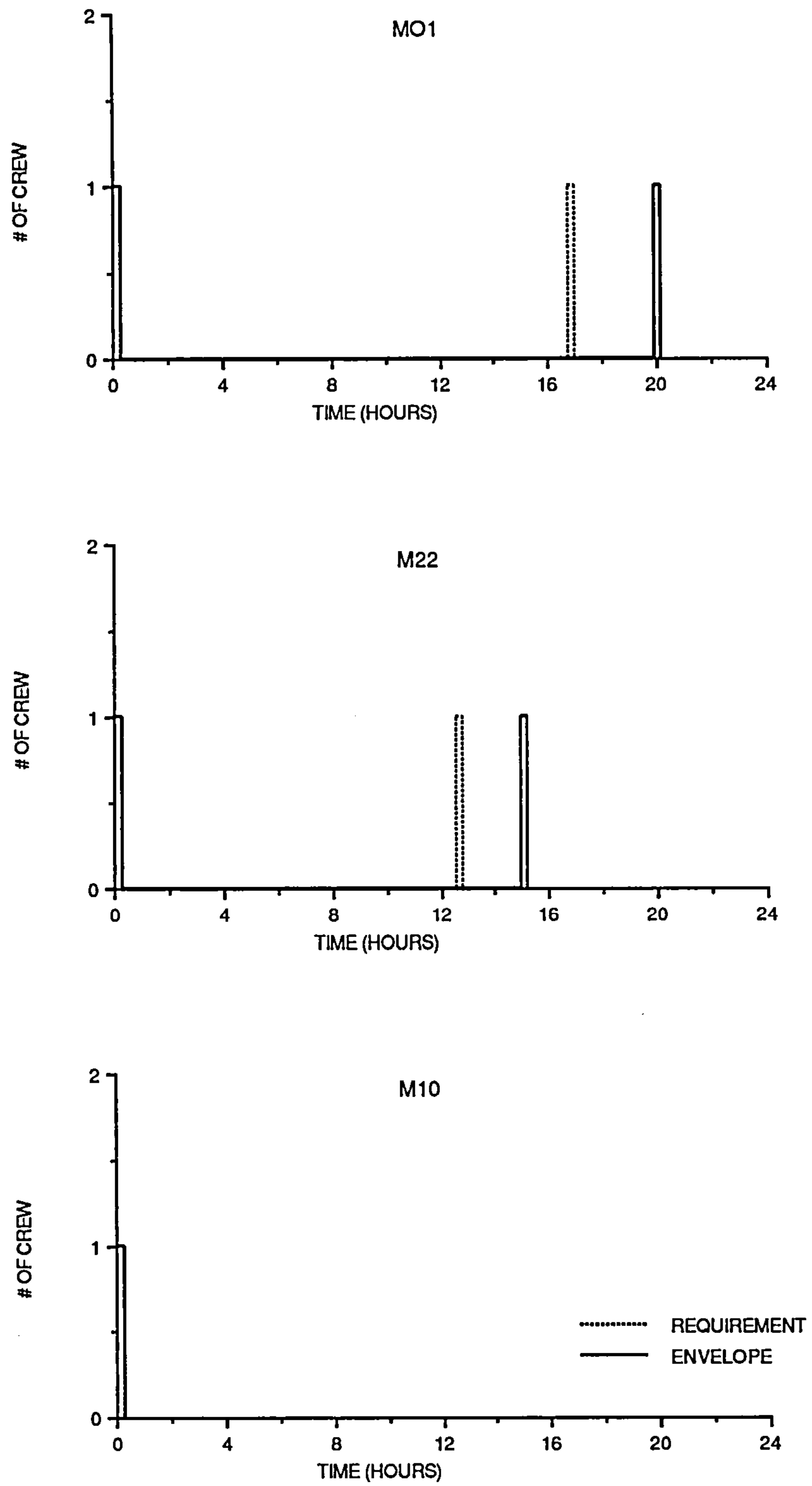


Figure 53. Individual activity crew envelopes – Method 7, case 3.

The increases in power and crew due to the activity envelopes are depicted in figure 54. Power increases 14 percent for M10 and 18 percent for M01 and M22. Crew increases 1 min for M10 and 3 min for M01 and M22. The increases represent the cost of the activity envelope.

The resource allocation for power and crew in the original models and that of Method 7, case 3, are compared in table 18. The fourth column indicates that the cost in power is 1.09 kWh for M01, 0.889 kWh for M22, and 0.195 kWh for M10. The cost in crew time is indicated in the seventh column. Crew is increased approximately 3 min for activities M01 and M22 and 1 min for M10.

The experiment envelope for power created by superimposing the individual activity envelopes for M01, M22, and M10 is depicted in figure 55. The experiment envelope for crew is depicted in figure 56. The envelopes allow resources for one performance of any one of the three activities.

The amount of resources in the experiment envelope which will not be utilized by the performance of a particular activity is the cost of the envelope. The marginal increases in power and crew for the experiment envelope are presented in figure 57. Power increases less than 1 percent for M01, 26 percent for M22, and 354 percent for M10. Crew increases 14 min for M01 and M22 and 28 min for M10.

Smoothing the experiment resource envelope for power was performed to simplify scheduling and to add flexibility. The arbitrary smoothing, as depicted in figure 58, resulted in an increase of 5.6 percent in power.

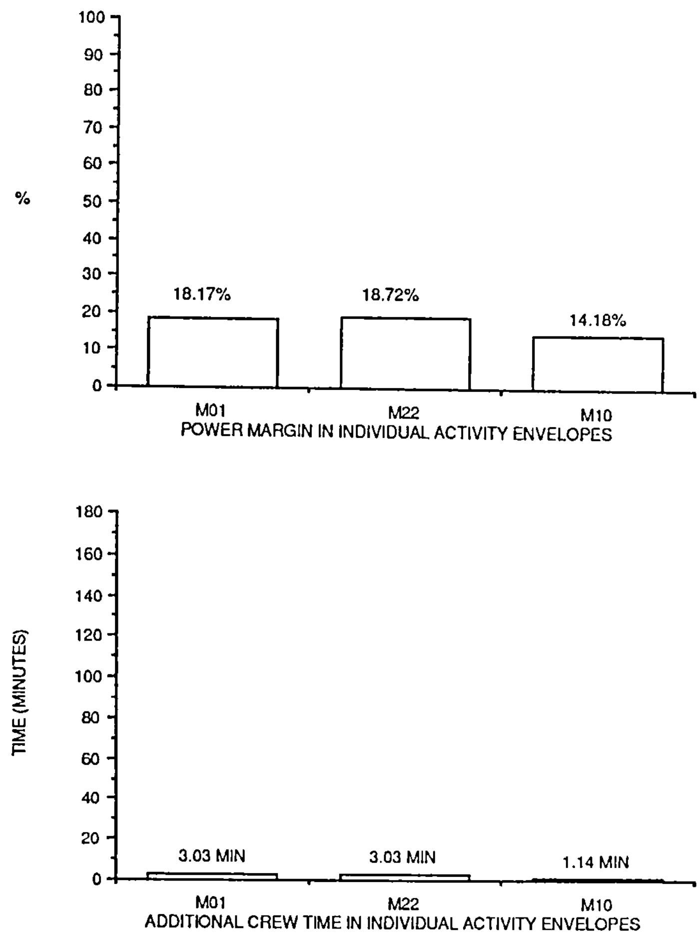


Figure 54. Power and crew resource envelope analysis – Method 7, case 3.

Table 18. Comparison of resource usage – original model and Method 7, case 3.

MODEL	ORIGINAL ENERGY (kWh)	METHOD 7 CASE 3 ENERGY (kWh)	COST IN ENERGY (kWh)	ORIGINAL CREW (min)	METHOD 7 CASE 3 CREW (min)	COST IN CREW (min)
M01	5.999	7.089	1.090	30	33.03	3.03
M22	4.748	5.637	0.889	30	33.04	3.04
M10	1.375	1.570	0.195	18	19.14	1.14

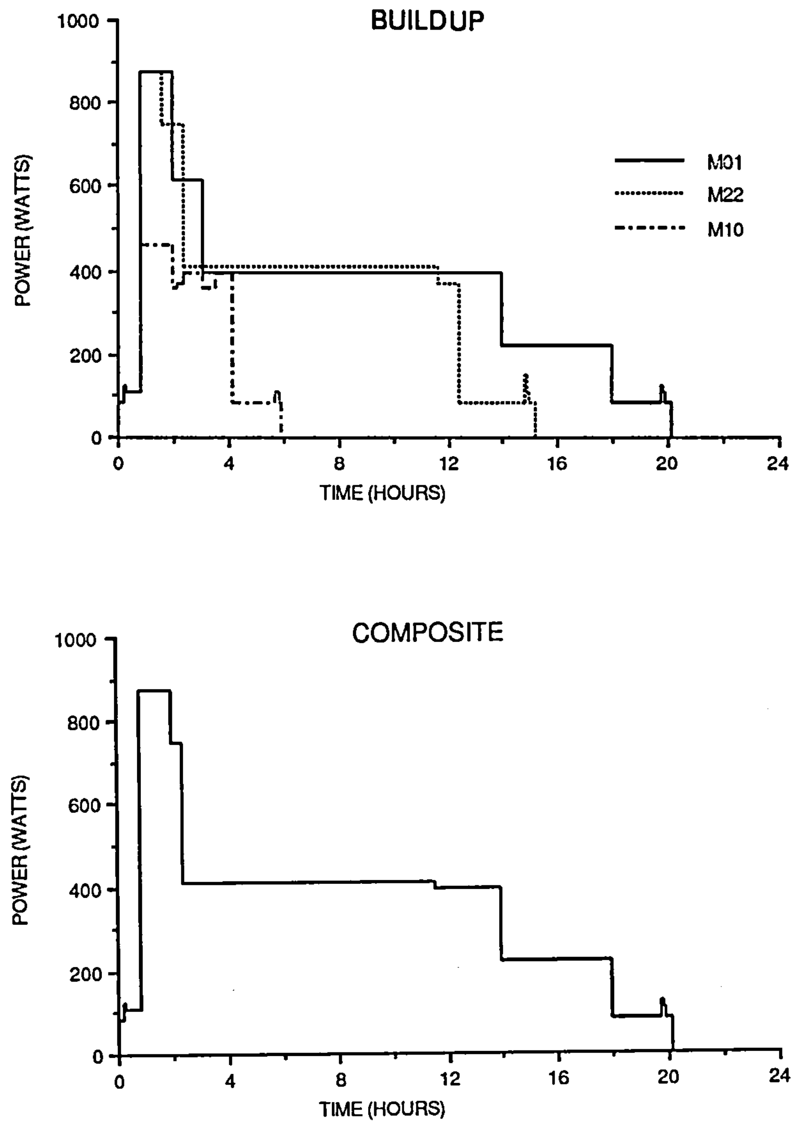


Figure 55. Experiment power envelope – Method 7, case 3.

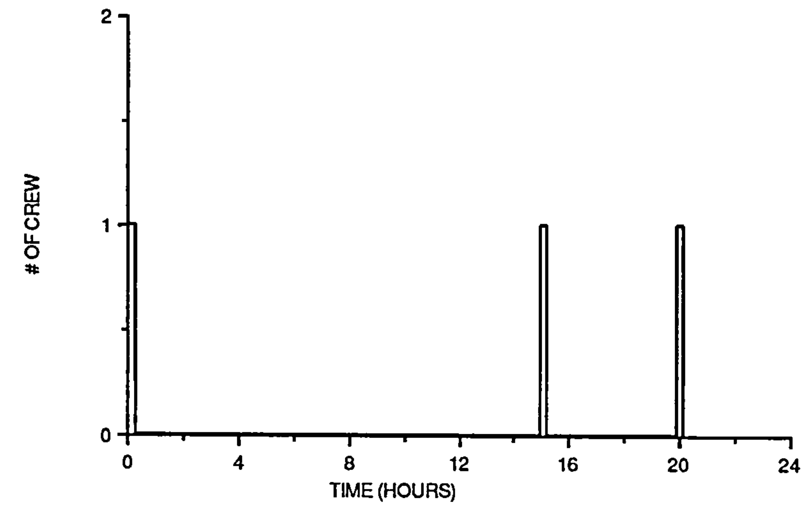


Figure 56. Experiment crew envelope – Method 7, case 3.

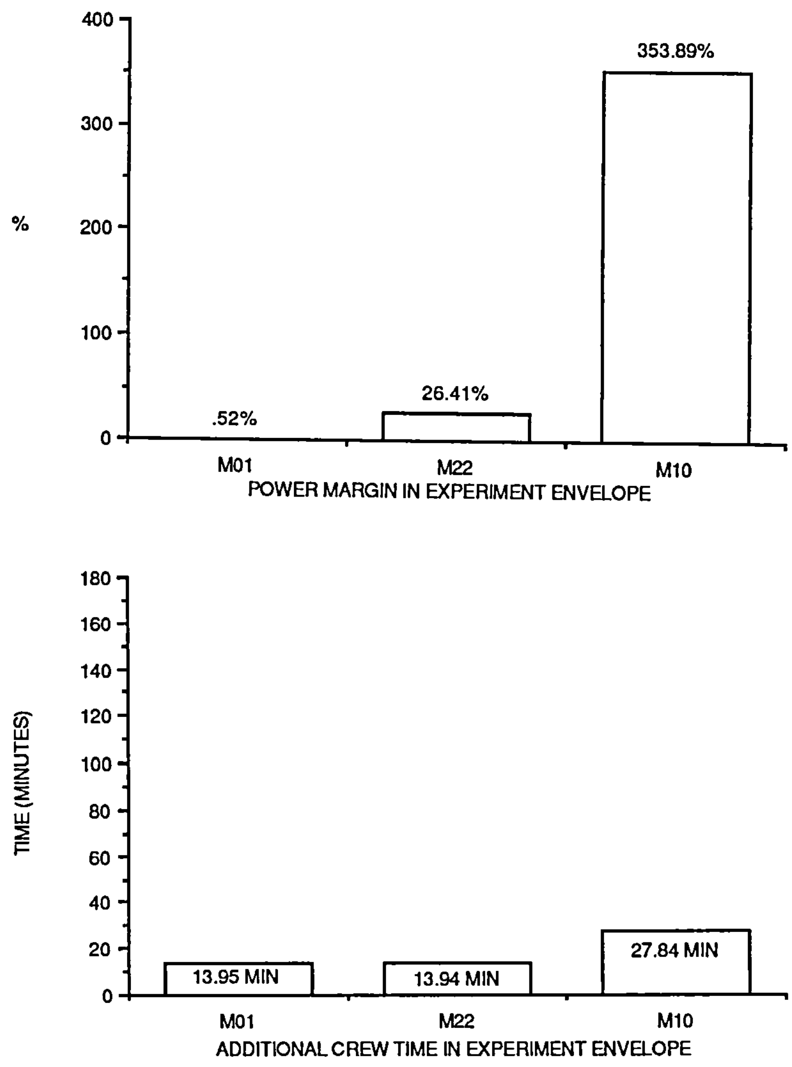


Figure 57. Experiment resource envelope analysis – Method 7, case 3.

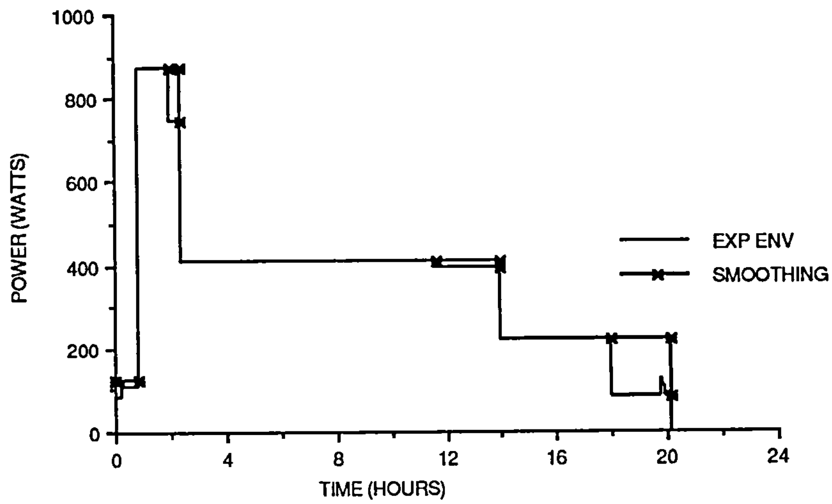


Figure 58. Smoothing experiment power envelope – Method 7, case 3.

Summary

Method 7, variable percentage step increase, provides the capability to assess several factors in determining the flexibility required. The method can be expanded, simplified, or modified to address more, less, or different factors. In addition, factors can be weighted to allow some factors to have a greater impact than others.

The three cases presented herein illustrate various methods of implementation. The activity envelopes created allow an increased run time with minimal increases in power and crew.

An experiment envelope was created for each case. The envelope allows for one performance of any one of the three activities. For each case, excess power in the envelope ranged from less than one percent to approximately 350 percent. Excess crew in the envelope ranged from approximately 15 to 30 min. As mentioned in previous methods, the experiment envelope could be modified slightly to allow an additional M10 performance. This would reduce the potential waste of resources.

Method 7 requires judgments to be made regarding the operational flexibility of steps and science priority of activities. Judgment must also be used in determining either the table percentages or the maximum step percentages.

CONCLUSIONS

Seven potential methods for creating resource envelopes have been analyzed showing benefits and costs in terms of resource utilization. Each method has advantages and penalties associated with its implementation. It is obvious that no single method will fulfill all the desires and requirements of the operational, investigative, and programmatic elements.

The seven methods discussed and a brief statement concerning each follows:

Method 1, Application of Fixed Length of Time, might be feasible for single experiments or classes of experiments, but by nature is inflexible to unique requirements.

Method 2, Variable Activity Durations, conserves resources by adding flexibility only where most needed, but its application is limited to specific classes of experiments.

Method 3, Application of Fixed Percentage of Time, provides an equitable manner of creating envelopes while doing so in relation to the resources required.

Method 4, Average Observation Opportunity, conserves resources by adding flexibility only where most needed, but its application is limited to specific classes of experiments.

Method 5, Increase Constraining Resource by Fixed Percentage, provides an equitable way to create envelopes for large numbers of activities/experiments.

Method 6, Increase Operationally Variable Steps, and method 7, Variable Percentage Step Increase, offer more complex, accurate methods of identifying where flexibility is needed and then creating the desired envelopes.

The seven methods presented can be modified to fit general classes of experiments or specific single experiments. The fixed length of time, percentage of time, and operational factors presented herein are for illustrative purposes only and can be tailored to fit classes of experiments or mission increments.

The resulting costs for each method presented are based on the attributes of the specific models used for illustration and the designated percentages and lengths of added time. Though these activities are representative of space station activities, different models will yield different results.

The activity and experiment envelopes for the methods presented herein were calculated manually. Due to the large volume of activities expected to be scheduled and the length of space station increments, software will be necessary to generate the envelopes.

The methods presented are the first step in providing a flexible, workable schedule for space station experiments. The cost of added flexibility through resource envelopes is a reduction in the amount of science scheduled for performance and potential wasted resources. The degree of flexibility which will eventually be incorporated into the schedule will be dependent upon feedback from the science user community.

It is hoped that discussion of the methods presented will generate suggestions from the user community concerning the amount of flexibility desired and how this flexibility can best be distributed. The compilation of these ideas will lead to the development of resource envelope methods which will generate mission timelines with optimal flexibility.

The Mission Analysis Division of the Mission Operations Laboratory at NASA/MSFC will be assessing the incorporation of resource envelope criteria into the S.S. *Freedom* program. The Mission Planning System being developed by MSFC will include assessments from future mission planning workshops, mission planning requirements, and review involving participation of the science user community. The resource envelope concepts must be reevaluated for the restructured S.S. *Freedom* program and the extended man-tended capability.

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16. Abstract

This document details seven proposed methods for creating resource envelopes for Space Station *Freedom* mission planning. Four reference science activity models are used to illustrate the effect of adding operational flexibility to mission timelines. For each method, a brief explanation is given along with graphs to illustrate the application of the envelopes to the power and crew resources. The benefits and costs of each method are analyzed in terms of resource utilization. In addition to the effect on individual activities, resource envelopes are analyzed at the experiment level.

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